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gives a square of 1·69 ft. side, the up-stream edge of which has been eased off to reduce the breadth of contact to about 8 in. In its upper portion, the thickness of the post is reduced to 1·18 ft., whilst its breadth remains constant; the upper and lower ends of the post are enclosed, the former in an iron, the latter in a bronze hoop, or rather rectangular band, having, in the case of the upper one, plates or notches capable of being laid hold of by a crow-bar when the gates are closed so as to bring them exactly opposite each other. The mode of fixing the cross-pieces to the mitre-post is identical with that adopted for the heel-post. The stout pieces of ironwork serving to fish the joints are similar, and are held by 1⅜-in. bolts.

Intermediate Posts.—These are formed of two half-posts connected with the cross-pieces in the manner described for the heel-post. Each half consists of two rectangular pieces. When it is required to put the four great portions of the leaves together, the intermediate half-posts are placed together and the eight indents or scarfing notches cut on their height, ensure their holding in the vertical direction. Iron fish-pieces indented into the two faces of the post, prevent the two halves from separating laterally. Thus composed, they have the following breadths throughout their height; next the heel-post 2·22 ft., in the middle of the leaf 2·16 ft., and next the mitre-post 2 ft. The thicknesses, which are variable, have been already given. These posts are bound with cast iron at their upper, and with bronze at their lower ends.

Principal Iron Pieces.—Allusion has already been made to the strong iron strips binding the end posts to the cross-pieces. They are of wrought iron, from 4⅜ in. to 5¼ in. broad, and 1¼ in. thick. The form of these pieces will be seen on Fig. 5156, and as they are let into the wood it will be noticed that they hold partly by their form. Upon the up-stream side of the five cross-pieces strips of iron from 6·30 in. to 4·72 in. broad are bolted to the tie-pieces on the opposite side with 2-in. bolts. The several pieces of which a cross-piece is composed are bolted together with horizontal and vertical 1¼-in. bolts. The chain attachments are 4·60 ft. above the wall and at the same distance from the end of the leaf, and therefore at a point near several iron strengthening pieces.

The Rollers.—Each leaf is supported upon two rollers placed one at a distance of 23·32 ft. from the pivot, and the other at twice that distance. They are both 11·8 in. broad, but are of different diameters, that of the one farthest from the centre of rotation being about 3 ft., and that of the other 2⅜ ft. The floor of the chambers is 3¼ ft. below the edge of the shutting sill; the portions beneath the pivots and roller paths are raised, as shown in the figure, for the purpose of keeping them free of accumulations of sand. The height of these portions above the floor is, including the rails of the the roller path, 14¾ in. The consequence of this is that the axles of the rollers are a little above the bottom of the leaf, in which a passage has been cut for the roller. The latter are placed a little towards the outside of the leaf in order to diminish the depth of the passage, and to bring the shaft to the roller-framing up to the face of the leaf to a bearing box provided with two regulating keys, and situate between the first and second cross-pieces. The roller paths are of a special form. Between their upper and lower faces, 12 in. and 36 in. broad respectively, there are a series of openings communicating with the top of the path so as to allow deposits of sand to drop down upon inclined planes, by which they are ejected from the cast-iron segments.

Sluices.—There are two sluices in each leaf between the two lower cross-pieces. They are of cast iron, and are 5 ft. broad. Two rods reaching to the top of the leaf, and connected there by a cross-head, and capable of being moved up and down by means of a screw and nut, form the working connections of the paddles.

Fenders.—The concavity of the down-stream face of the gate protects it from the friction of passing vessels. But for greater security, vertical pieces are fixed against the tie-beams over the intermediate posts. These pieces are nearly square in section and are of deal, as they do not give additional strength, and, besides, are not needed on the lower third of the leaf.

Foot-path Platform.—The foot-path platform is about 6 in. above the side walls, and has a breadth of 4 ft. 6 in. throughout the length of the leaf. It is supported at intervals upon the top cross-piece by cast-iron supports. The two hand-rails are each formed of ten wrought-iron standards connected at the top and in the middle by chains, as shown in the figure. Each chain is fixed to one standard by an eye-bolt, and is hooked to the next. The standards are supported in small deep sockets upon the face of which they rest by a broad base. This arrangement, which is everywhere adopted in the Mersey Docks, enables them to be easily and quickly taken down and replaced.

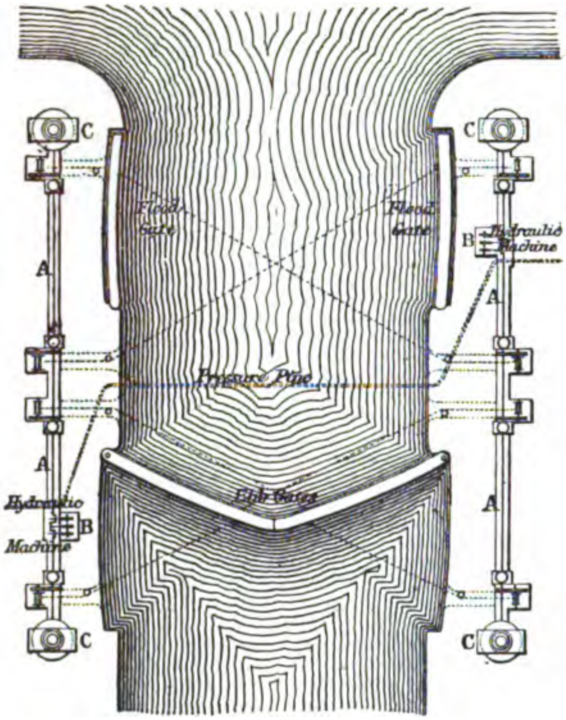
Weight and Volume.—Each leaf contains 3516 cub. ft. of green-heart timber, the weight of which is about 113 tons. The weight of the iron used in the construction is 22 tons. The total weight of a leaf is therefore 135 tons. The total volume of the leaf may be taken as 3637 cub. ft. Under ordinary circumstances the immersed portion corresponds to the level of the top of the fourth cross-piece, and its volume is about 2860 cub. ft.; thus the lessening of the weight is about 81 tons. Hence it follows that the weight upon the pivot and the two rollers is 54 tons, say, in round numbers 18 tons upon each roller. These gates are opened and shut by hydraulic machinery, and the operation requires three minutes.

The Wrought-iron Gates of Jarrow Docks upon the Tyne, Figs. 5160 to 5162.—These gates were constructed in 1858 on the model of the Victoria gates, but with certain improvements which obviated the grave defects possessed by the latter.

The Wrought-iron Gates of the Grand Surrey Docks, London, Figs. 5163, 5164.—These gates are remarkable for a peculiar construction both of the leaves themselves and of the horizontal and vertical diaphragms of which their framing is composed. The former are curved, but have on the concave side a straight tie-piece, constituting the chord of the arc, which struts against a straight sill. The latter, with the exception of those enclosing the water-tight chambers, have *lattice-webs*. The leaves are, like those of the Jarrow Dock gates, curved at the bottom, so as to raise the pivots clear of all obstructions, and they support, in ordinary equinoctial tides, a pressure resulting from a difference of level of 20 ft. The angle formed by the two leaves being 148°, it follows that the

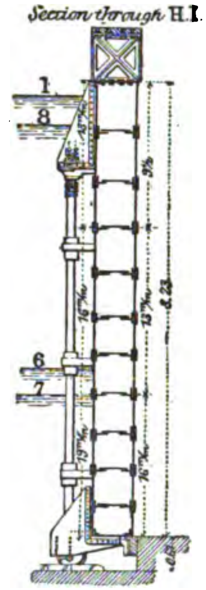
versed sine of the arc is only about one-seventh of the span. Each leaf has nine and eleven horizontal compartments between the heel and mitre posts, the wooden facings of which are of oak.

5160.



5162.

Section through H.I.



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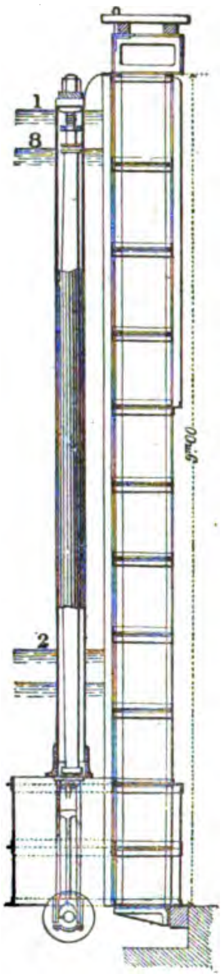
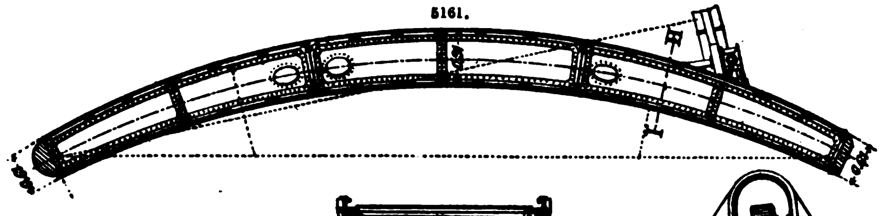
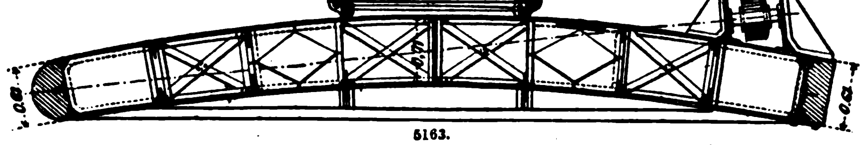


The vertical diaphragms are numerous, there being, besides the two end ones, seven intermediate. The angle-irons employed are 3 in. by $\frac{7}{16}$ in. thick. The roller is external to the curve, as in the case of the Victoria Dock gates, and is 2 ft. in diameter and 6 in. broad. Its regulating support is a vertical hollow column of cast iron, of 10 in. diameter in the middle, where it is greater than at the ends, and 1 in. in thickness. The upper portion of the down-stream side of the leaf is protected by creosoted planks 4 in. thick and 14 ft. long. The principal dimensions are;—Span, 50 ft.; height of the leaf above the mitre-point, 29·5 ft.; thickness of the leaf in the middle, 2·42 ft.; thickness at the ends, 2 ft. The thickness of the skins varies between $\frac{3}{8}$ and $\frac{5}{16}$ in. Each leaf weighs 52 tons; it displaces at high water 49 tons, and at low water 20 tons. The weight of iron in a leaf is approximately 45 tons.

5161.





5163.

Having described the nature and construction of some of the most important lock-gates now in existence, S. Périssé, in the paper before referred to, considers which of these types may be adopted as the best. But first it is desirable to determine the most suitable span, or rather its limits, since

the breadth of locks cannot be absolutely uniform. It may be admitted, however, writes Périssé, that in harbours already possessing large entrances, it would be useless to exceed the breadth of 70 ft. in future. It must be observed that the floor of locks is nearly always curved in the form of an inverted arch, in order to resist better the under pressures; and the exaggeration of the breadth would allow the passage of large screw-steamers, the adoption of which seems to be getting general, to pass out of the axis of the lock, that is, get into a part where the depth of water is less. But, on the other hand, it is desirable not to go below 55 or 60 ft., if we wish to be prepared for possible future requirements; 60 ft. appears a good mean.

As to the best type of gate, it is evidently that which utilizes the assistance that the vertical lends to the *horizontal, equal, and equidistant cross-pieces*. The advantages of this compound system are indisputable in the case of wrought-iron gates. But the advantage is not so apparent in the case of wooden gates. It is more difficult to procure a series of pieces of the same than of various dimensions; and the lightness of wooden gates increases with the volume displaced in neap tides, and when the cross-pieces are equidistant, this volume evidently decreases. Wooden gates with equidistant cross-pieces are therefore heavier.

With regard to the question of *form*, whether straight or cylindrical, of the cross-pieces, it may be remarked that curvature gives a smaller quantity of material, and is more economical for wooden gates, notwithstanding the greater cost of the shutting sills. But in the case of iron gates this economy is purely theoretical; it does not exist in fact, first, by reason of the necessity of giving a greater thickness to the skins than curved leaves would require, and, second, the curvilinear form on both sides increases the difficulties of construction in iron leaves, which, it must not be forgotten, have to be water-tight in their air-compartments. Périssé is of opinion, therefore, that in iron gates the cross-pieces should be straight on the side farthest from the pressure. In wooden gates the cylindrical form has the disadvantage of not allowing the use of suspension ties, which are indispensable for suspension gates. But when rollers are used, curved leaves of green-heart timber, like those on the Mersey, should be preferred to all others, on account of the great durability of green-heart in sea-water, and the possibility of employing timber of all dimensions.

Nature of the Materials.—A careful calculation of cost will show that wrought-iron gates are the least expensive; and we saw in the case of the Boulogne gates that they possess the following advantages;—1. Any degree of lightness obtainable by increasing the dimensions of the air-chamber. 2. Greater rigidity. 3. Capability of being more easily moved, and at any height of the tide, when the gates are upon rollers. 4. Capability of being rendered heavier if required, to resist the action of waves. 5. Constant load upon the pivot and roller, unless in exceptional circumstances. 6. Possibility of suspending them without suspension ties, as the skins may serve the same purpose. 7. Facility for examination and repairs. 8. Greater durability.

This enumeration is conclusive in favour of iron gates as compared with wooden gates. As for those which we have called mixed or compound, they ought certainly to be abandoned.

Wooden gates, however, have still numerous partisans. They are more easily constructed and replaced. It may be objected that iron gates have to be constructed in the upright position, and that this constitutes a difficulty in case of replacing, and a greater expense, as wooden gates may be constructed in the horizontal position. To this it may be answered;—1. That the upright position was adopted for the second wooden gates at St. Nazaire, and that the operation of letting them down was perfectly successful; and, 2. That if the cost of erection is greater, the saving resulting from the superior durability is much greater still.

In fine, wrought-iron lock-gates are preferable in maritime ports, unless the dimensions are to be very small, in which case the leaves would not be sufficiently thick to be readily accessible in all parts. The thickness of the iron shell near the posts should not be less than 2 ft., to be increased towards the middle as indicated by the calculation of the strains. There will always be a practical advantage in exaggerating, so to speak, the thickness of the leaf, provided we reduce the webs of the horizontal diaphragms to $\frac{5}{16}$ in. or $\frac{11}{32}$ in., or form them of lattice, with the exception, of course, of the one which closes the air-chamber. Above the chamber the iron plating forming the skin, no longer indispensable, may be suppressed, either upon the down-stream side only, or upon both sides, and wooden planks substituted, placed close together, and calked on the up-stream side, whilst on the opposite side they would be placed a distance apart. In such a case the injury caused by vessels coming in contact with them would be of small importance, as repairs might be quickly and cheaply effected. This arrangement would effect a considerable saving, and would not suppress one of the advantages pointed out, if the precaution were taken to introduce into the upper iron framing oblique pieces, to form trussings and bracings, in the case of the gates being suspended.

It will be advisable to exclude the employment of angle-irons less than 3 in. × 3 in. in all the important parts, in order to be able to use $\frac{3}{4}$-in. rivets; and the wood facings of the post and shutting sill should be of green-heart timber.

Canal Locks.—The following are some of the ordinary dimensions and proportions of canal locks;—The mitre-sills should rise from 6 to 9 in. above the floor; the versed sine of mitre-sill, from $\frac{1}{5}$ to $\frac{1}{6}$ of breadth of lock; and the clearance in depth of the recesses for the gates be $\frac{1}{10}$ of thickness of gate; clearance in length, $\frac{1}{4}$ of length of gate. Least thickness of the side walls at the top, about 4 ft. Greatest thickness at the base, fixed according to the principles of the stability of walls, usually from $\frac{1}{3}$ to $\frac{1}{2}$ of the height. Length of side walls of head-bay above gate-chamber, about $\frac{1}{3}$ of breadth of lock. Large counterforts opposite hollow quoins to have stability enough to withstand the calculated *transverse thrust* of the gates. The *longitudinal thrust* of the head-gates is borne by the side walls of the lock-chamber; that of the tail-gates by the side walls of the tail-bay. To give the latter walls sufficient stability, the rule is to make their length as follows;—Breadth of lock × greatest depth of water + 15 ft. · Versed sine of lift-wall, from $\frac{1}{12}$ to $\frac{1}{8}$ of breadth of lock. Floor of head-bay; least thickness, from 10 in. to 14 in. Floor of lock-chamber; versed

sine, about $\frac{1}{15}$ of breadth; thickness, from $\frac{1}{15}$ to $\frac{1}{8}$ of breadth, according to the nature of the foundation.

Foundations of various kinds have been sufficiently explained. It has only to be added that when a lock is founded on a timber platform, longitudinal pieces of timber extending along the whole length of the foundation are to be avoided, lest they guide streams of water along their sides; that transverse trenches under the foundation, filled with hydraulic concrete, are a good means of preventing leakage; and that, in porous soils, the whole space behind the lift-wall and under the floor of the head-bay may be filled with a mass of concrete.

Length of apron from 15 to 30 ft.

The dimensions of the different parts of the gates are to be computed according to the principles of the strength of materials. It appears that the factor of safety in many actual lock-gates is as low as 3 or 4. This can only be sufficient by reason of the perfect steadiness of the load.

See CANAL. DOCKS. HYDRAULIC MACHINES. MATERIALS OF CONSTRUCTION, *Strength of*.

LOCK-CHAMBER. FR., *Chambre d'écluse*; GER., *Schleusenkammer*; SPAN., *Esclusa*.

The enclosed space between lock-gates into which vessels enter, is the *lock-chamber*.

See DOCK. LOCKS AND LOCK-GATES.

LOCOMOTIVE. FR., *Locomotive*; GER., *Locomotive*; ITAL., *Locomotiva*; SPAN., *Locomotora*.

No combination of mechanism to transmit power has effected so complete a revolution in human affairs as the locomotive. The honour of claiming such an immeasurably great invention has been much coveted, as giving lustre not only to the particular family of the inventor, but also to his nationality; and accordingly the most plausible arguments have been used, and the utmost ingenuity exercised to take the credit from its legitimate possessor. To Richard Trevithick is the merit of inventing the locomotive really due. He, about the year 1801, experimented with a working machine for locomotive purposes, acting solely by the expansive force of steam; in 1802, he, in conjunction with A. Vivian, patented the invention, and in 1803 actually ran the locomotive in the streets of London. The locomotive was not a commercial success in Trevithick's hands, but since his time it has been improved by inventors too numerous to mention, and it is now the principal means of land transport in use throughout the world.

The chief parts of a modern locomotive steam-engine are;—

The boiler, partly filled with water for the generation of steam.

The engine proper, by means of which the action of the pressure of the steam is changed into the motion of the working parts of the engine, which consists of steam-cylinder and valve gear.

The framework, carrying boiler and engine, and consisting of frames with springs, horn-plates, buffers, axle-boxes, and like details, and the wheels and axles.

These parts are common to all locomotives, which may in general be classified as express engines, representing speed; goods engines, representing loads to be drawn; and, further, as passenger engines, combining a moderately high speed with a considerable traction power, and used for mixed trains, or trains running only over short distances, between stations.

These three classes of engines must necessarily be so constructed as to carry with them sufficient fuel and water, to enable them to run over a certain distance without prolonged stoppages. Express and goods engines are always provided with a separate vehicle for carrying fuel and water, called the *tender*. Passenger engines are often constructed so that they are provided with water-tanks and coal-bunkers, thus requiring no extra tender. Engines constructed in such a manner are called *tank engines*.

These classes are all subject to change in the arrangement, and in this respect may be also generally divided into locomotives with *outside* cylinders, and locomotives with *inside* cylinders; that is to say, locomotives in which the steam-cylinders are placed either *outside* the frame-plates, or *between* the frame-plates. In the former case all the axles of the locomotive are straight, the cranks being fixed at the extreme ends of the driving axles, or are formed by one of the spokes of the driving wheels, whilst in the latter case the cranks have to be placed between the two driving wheels, thus requiring *cranked axles*.

Figs. 5165 to 5193 represent the type of a complete engine and tender, in which almost all parts of a locomotive may be found to be represented, and indicated by corresponding numbers. The figures show an express engine, as built for the Great Northern Railway from the designs of Patrick Sterling, locomotive superintendent to that company. The following are the names of the various parts;—

The three main parts of the boiler, Fig. 5171, are;—

1. Barrel of boiler.
2. Fire-box.
3. Smoke-box.

The barrel consists of—

4. The shell of the boiler.
5. Heating tubes, in the present case 217 tubes.
6. Casing of the boil
7. Man-hole.

The fire-box, Fig. 5172, consists of—

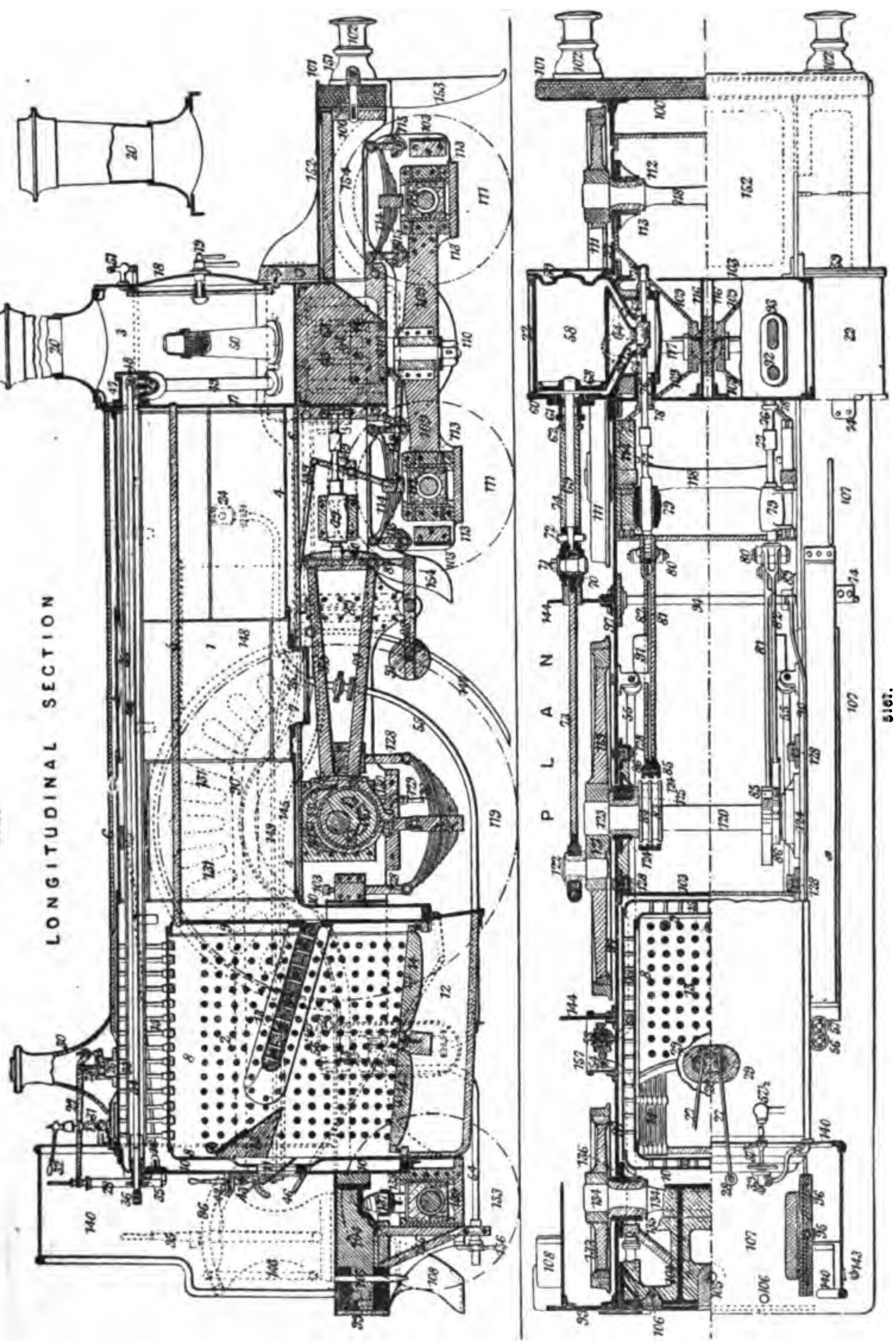
8. Inside fire-box, with
9. Tube-plate.
10. Outside fire-box.
11. Fire-door, Fig. 5173.
12. Ash-box.
13. Fire-bridge.
14. Fire-grate, with bars and cross-pieces.
15. Roof-stays.
16. Longitudinal stays.

The smoke-box, Figs. 5171, 5174, of—

17. Tube-plate at smoke-box end of boiler.
18. Smoke-box door.
19. Smoke-box door fastening.
20. Funnel.
21. Shell of smoke-box.
22. Casing of smoke-box, forming in its continuations cylinder casings.

The fittings of locomotive-boilers are, for the barrel—

23. Brackets for hand-rails, Fig. 5175.
24. Delivery or admission valve of feed-water.
25. Place of discharge cock.

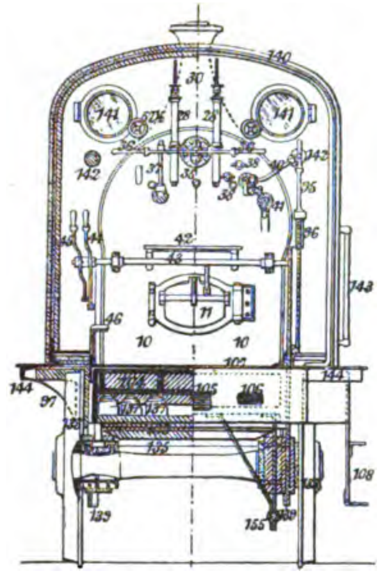


5165. LONGITUDINAL SECTION

5166.

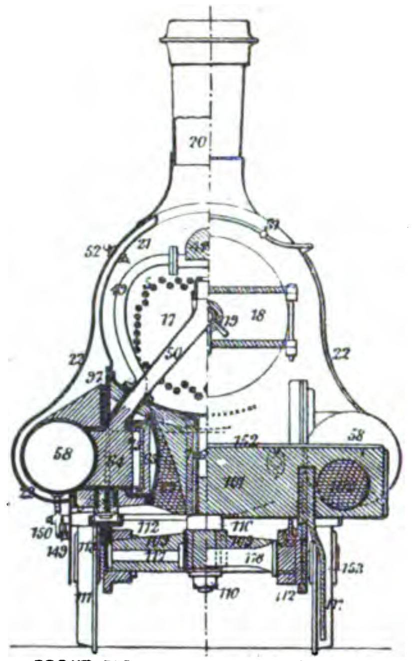
5167. PLAN

5168.



BACK ELEVATION — PART IN SECTION

5169.

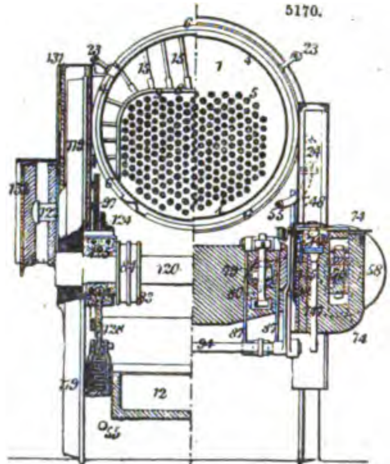


FRONT ELEVATION — PART IN SECTION

For the fire-box, Fig. 5176;—

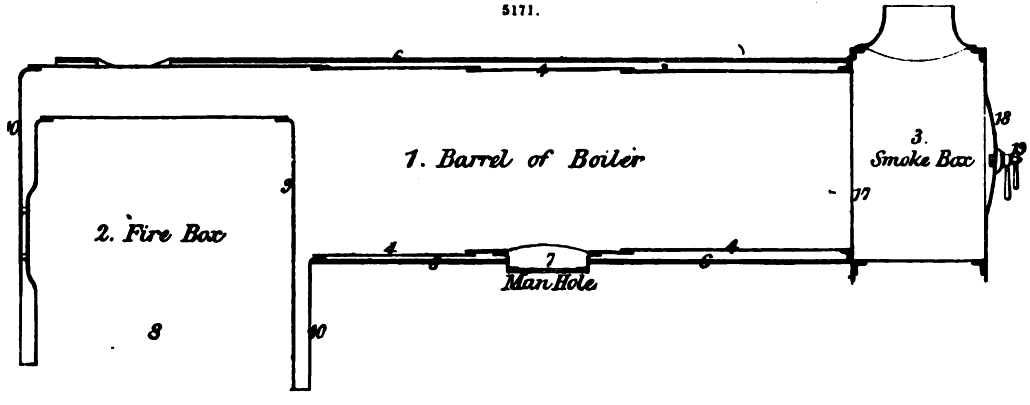
26 Safety-valve seat.
27 Lever of safety-valve.
28 Spring, and spring case, for safety-valve.
29. Safety-valve.
30. Casing for safety-valve.
31 Steam-whistle.
32. Handle for steam-whistle.
33. Regulator-tube, Fig. 5177.
34. Regulator-rod.
35. Stuffing box, and gland of regulator.
36. Levers of regulator.
37. Water-gauge, glass, and cocks, Fig. 5168.
38. Steam-cocks.
39. Steam-cock in connection with
40. Steam-pipe for the admission of steam into one of the hollow hand-rails, an arrangement by means of which steam is injected into the funnel of the smoke-box for the purpose of promoting or improving the draught through the fire-tube when the locomotive is standing still.
41. Water-discharging cock and tube.
42. Heat and fire protecting plate.

5170.



SECTION AT DRIVING AXLE | SECTION AT VALVE MOTION

5171.



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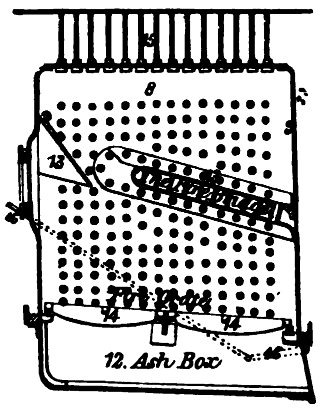

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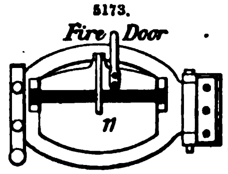

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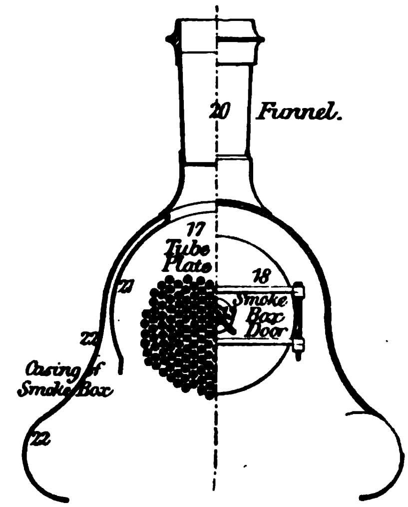

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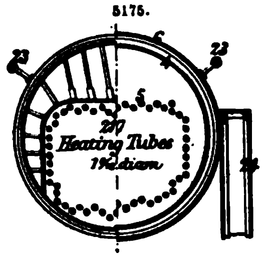

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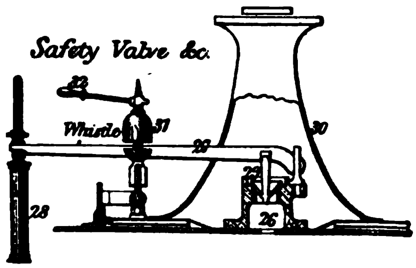

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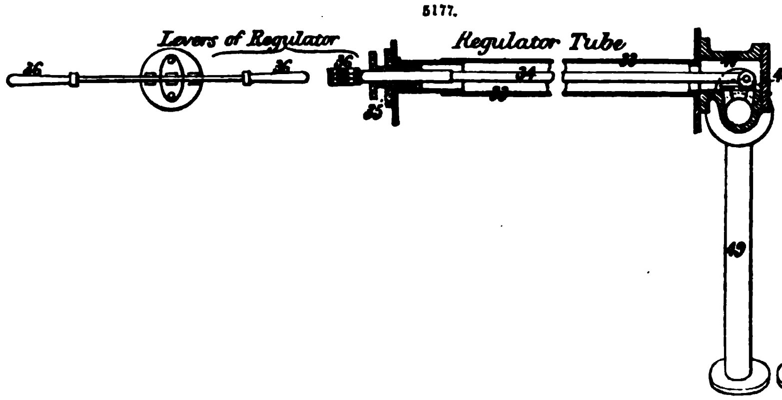

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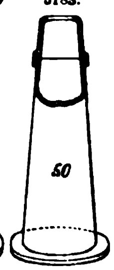


43. Common axle to—
44. Lever for opening the dry-sand box, and
45. Lever in connection with the cylinder-cocks.
46. Levers for opening ash-box.

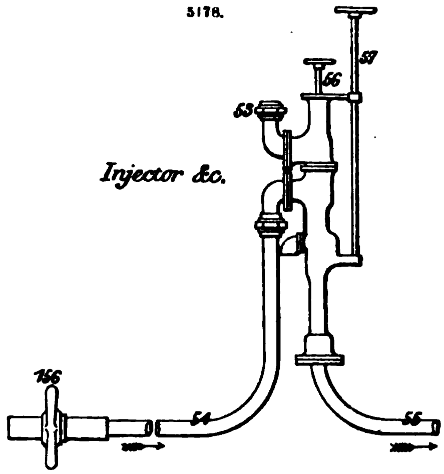
For the smoke-box ;—
47. Regulator-box.
48. Regulator-valve.
49. Steam a·lmission pipe from regulator to cylinder.
50. Exhaust-pipe from cylinder, Fig. 5183.
51. Hand-rail.
52. Hollow hand-rail and pipe in connection with 39 and 40.

For the boiler in general ;—
53. Injector, Fig. 5178.
54. Water-pipe from water-tank to injector, connected to
55. Water-pipe from injector to boiler.
56. Handle and screw for regulating the admission of water.
57. Handle and screw for regulating the admission of steam.

57½. Valves, with handles and screws, for admitting steam into the injector.

The engine proper consists of—
58. Steam-cylinder, Fig. 5179.
59. Bottom of steam-cylinder.
60. Top of steam-cylinder.
61. Stuffing box of steam-cylinder
62. Gland of steam-cylinder.
63. Admission-ports.
64. Exhaust-ports.
65. Steam-chest.
66. Valve-face.
67. Steam-chest cover.
68. Piston.
69. Piston-rod.
70. Cross-head.
71. Cross-head pin.
72. Piston-rod cotter.
73. Connecting rod, Fig. 5180.
74. Motion-bars.
75. Valve.
76. Valve-spindle.
77. Valve-rod.
78. Stuffing boxes for valve-spindle.
79. Guide-bracket for valve-rod.

5178.



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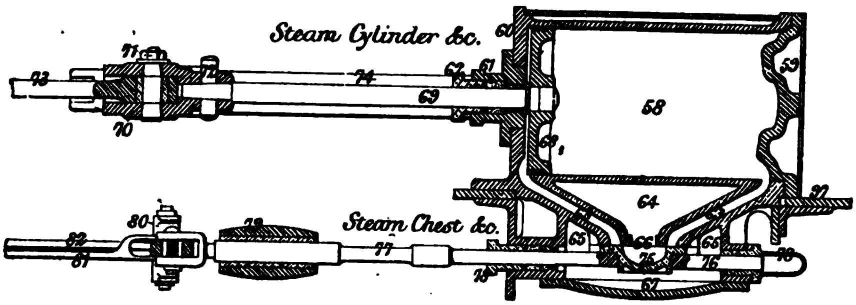

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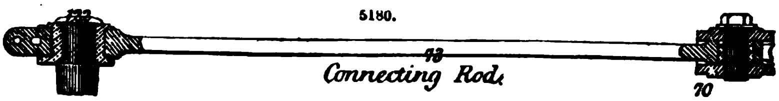

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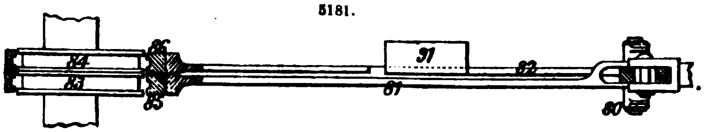

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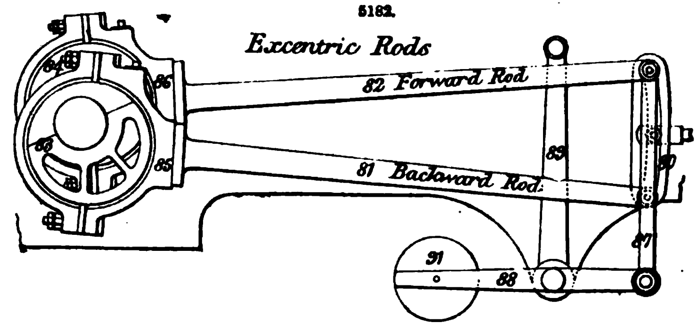


Figs. 5181, 5182—
80. Link.
81. Eccentric-rod for backward motion.
82. forward
83. Backward excentor.
84. Forward excenter.
85, 86. Eccentric-rings.
87. Suspension-lever.

88, 89. Rocking levers.
90. Reversing rod.
91. Counterweight for rocking lever.
92. Steam admission.
93. Steam exhaust.
94. Rocking shaft.
95. Reversing lever, with
96. Graduated arch for reversing lever.

Framework is formed of the frames—
97, 98. Longitudinal frame-plates.
99. Buffer-plate at trailing end.
100. „ „ leading end.
101. Buffer-beam.
102. Buffers.
103. Cross frame-plates.
104. Cast-iron block-plates for fastening draw-pin.
105. Draw-pin.
106. Places for safety-chains.
107. Foot-plates.
108. Foot-steps.

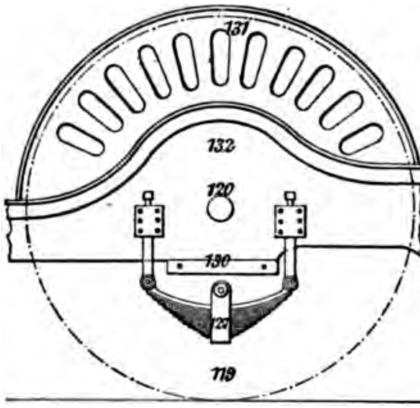
Bogie—
109. Bogie-frame.
110. Bogie-pin.
111. Wheels of bogie, or leading wheels of engine.
112. Bogie axle-boxes.
113. Guides of axle-boxes.
114. Bearing springs of bogie-wheels.
115. Spring harness.
116. Bogie pin-plates.
117. Cross-stays for bogie-pin.
118. Axles for bogie-wheels.

Driving wheel and axle, Figs. 5184 to 5186;—
119. Driving wheel.
120. Driving axle.
121. Crank, cast together with boss of driving wheel.
122. Crank-pin.
123. Bearings of driving axle.
124. Guide-blocks of bearings.
125. Adjusting block, or wedge of bearings.
126. Bearing spring of driving axle.
127. Shoe of bearing spring.
128. Spring harness.
129. Adjusting screw for wedge 125.
130. Horn-plates.
131. Driving-wheel cover.
132. Crank-pin cover.

Trailing wheels, Figs. 5187 to 5189;—
133. Trailing wheels.
134. Trailing axles.
135. Bearing for trailing axle.
136. Guide-plates for bearings.
137. Spiral springs for trailing end of engine.
138. Frame for carrying spiral springs.
139. Horn-plates for trailing axle.

The engine has in addition;—
140. Cover for protecting stand of driver.
141. Awnings or eye-glasses for drivers.
142. Hand-rail fastenings.
143. Upright hand-rail.
144. Angle-irons, and brackets for carrying foot-plates.
145 Rod for opening sand-box valve in connection with 44.
146. Sand-box valve.
147. Sand-box pipe.
148. Sand-box.
149. Rod and lever for opening cylinder-cocks in connection with 45.

5184.



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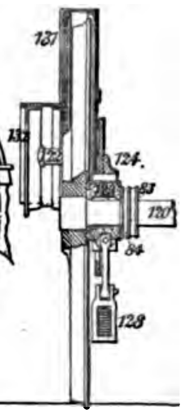
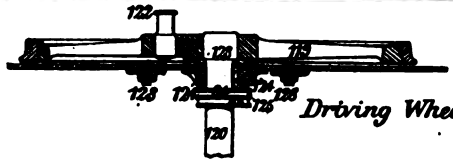
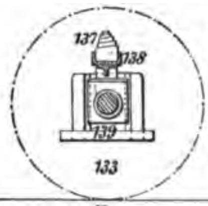


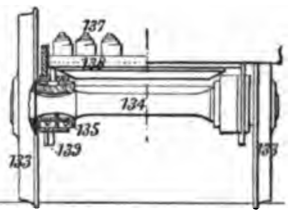


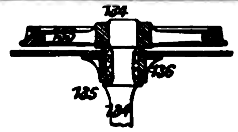
Driving Wheel &c.

5186.

5187. 5188.







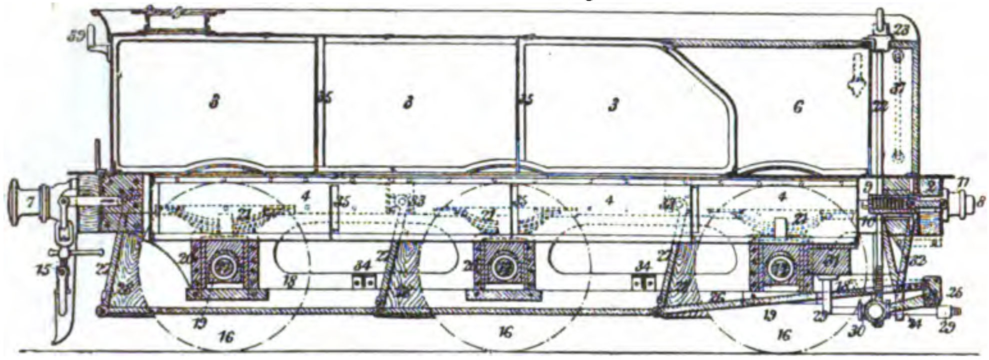
Trailing Wheels.

5189.

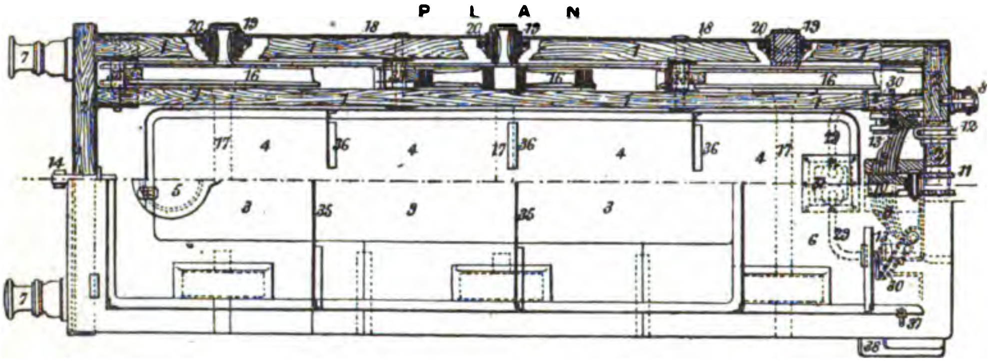
150. Cylinder-cocks.
151. Pin for coupling chain.
152. Plate on top of frame at bogie, or leading end of engine.
153. Guard-rails.
154. Covers for bogie or leading wheels of engine.
155. Hangers for carrying water-pipes.
156. Screw-joint for water-pipe.
157. Cover for protecting injector.

Figs. 5190 to 5193 are of the tender and its fittings;—
1. Longitudinal timber frames.
2. Cross timber frames or buffer-beams.
3. Upper water-tank.
4. Lower water-tank.
5. Filling hole.
6. Coal-bunker.
7. Buffers.
8. Buffer between engine and tender.
9. Draw-spring.
10. Shoe of draw-spring.
11. Draw-hook or link.
12. Safety-chain in connection with 106 of engine.

5190.
ELEVATION



5191.
PLAN



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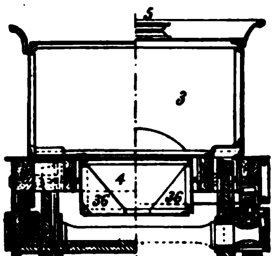
SECTIONS



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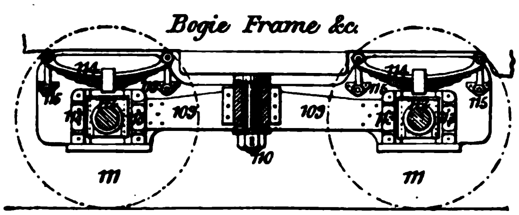


13. Links for draw-springs.
14. Draw-bar.
15. Coupling.
16. Wheels.
17. Axles.
18. Wrought-iron frame-plates.
19. Axle-boxes.
20. Guide-blocks.
21. Bearing springs.
22. Brake-spindle.
23. Bracket for brake-spindle.
24. Fork for brake-shaft.
25. Brake-shaft.
26. Brake-rods.
27. Brake-levers.
28. Brake-blocks.
29. Water-pipes.
30. Stop-valve in water-pipes.
31. Water supply box.
32. Brackets for carrying water-pipes.
33. Pins for brake-levers.
34. Cross-pieces between wrought-iron frame-plates.
35. Partition in water-tanks.
36. Upright brackets in water-tanks.
37. Upright hand-rail.
38. Foot-steps.
39. Lamp-iron.

One of the remarkable facts of the present time in connection with locomotive engines is the increasing tendency to resort to heavier and more powerful types. The greater dimensions of these engines, however, necessitate an increased number of axles, and hence we hear of locomo-

tives having four, six, eight, and even twelve coupled wheels. It is true that such engines are to be found chiefly in foreign countries whose natural peculiarities may in some measure justify their adoption, and that in this country such extreme dimensions are looked upon with disfavour. But though there is little probability of our adopting in its entirety the practice of other nations in this respect, there is a growing disposition to have recourse to engines supported upon more than three pairs of wheels for heavy work. In the following figures all marked dimensions are metric.

Engines with eight coupled wheels.—Fig. 5208 represents the ordinary type of goods engine employed by the French Northern Railway Company on their lines having large curves. The remarkable features of this engine are, its long barred fire-box, on Belpaire's system; the position of the trailing axle beneath the fire-box; the fixing of the brake upon the engine instead of upon the tender; and the placing of the mechanism on the outside. The frame-plates are between the wheels inside. The piston-rods, connecting rods, and other parts of the mechanism, are of cast steel. The eight axles are without a movable joint, but the end wheels have a little lateral play in the grease-boxes.

Fig. 5212 represents the class of goods engine in use upon the Russian railways, and may be taken as an illustration of the pure German type. The framing as well as the whole of the mechanism is outside the wheels. The cranks are upon the ends of the axles, and arranged according to Hall's system. The frame-plates consist of two cheeks of plate iron ⅜ in. thick, having between them a strip of rolled iron 7½ in. in depth and 1½ in. thick. The chimney is of the form common in America for burning wood. Among other features worthy of notice may be mentioned the great length of the boiler, the slide-valve on Allen's system, the wooden floor of the platform, and the shelter provided for the driver, the levers of the safety-valves called Egenhoffen's, the counter-rod of the piston, and the special kind of Giffard's injector. The weight is distributed as follows;—Upon the leading axle 11 tons, upon the second 12 tons, upon the driving axle 13 tons, and upon the trailing axle 12 tons.

Fig. 5209 is a tank engine of the Great Northern Company, and may be taken as a representative of the class of eight-wheeled locomotives which English engineers have begun to adopt. The mechanism, as usual in this country, is inside; its main features are a large fire-box, supported in the middle by the trailing wheels and longitudinal tanks. Several of these engines have been constructed for India and Wales. In some of these latter a little play is allowed the end axles, to enable the engine to run smoothly over curves.

Engines with six coupled wheels.—Fig. 5211 is a specimen of this class by the Company of the Southern Railway of France. The boiler of this locomotive is of steel, 9 millimètres, or about 0·35 in., thick; it contains 4 cub. mètres, 880 gallons, of water, and 1980 litres, 70 cub. ft., of steam. The grease-boxes and the guide-supports are of bronze. The cylinders are outside, and the framing and the mechanism of the slide-valve, which is on Allen's system, are between the wheels. The great diameter of the latter is also a noteworthy feature. The leading wheels may be removed and replaced by others uncoupled, for the purpose of readily converting the engine into one suitable for lighter work. The weight of the engine is disposed as follows;—11 tons on the leading, 12 on the driving, and 11 on the trailing wheels.

Fig. 5194 represents a tank engine constructed at the well-known Creusot Works, and exhibited in 1867 at Paris. This engine is designed for heavy goods-traffic upon short branch lines with sharp gradients, and is worthy of remark as a specimen of its class, which has been largely supplied from these works to Russia, Italy, Spain, and Belgium. The whole of the mechanism is outside, reminding one of Engerth's system. The water-tanks are upon each side of the barrel of the boiler. It is said that this engine is capable of drawing a useful load of 700 tons upon a level way.

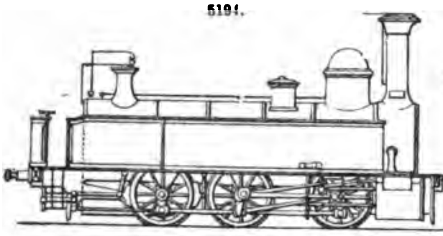
Engines with four coupled wheels.—This class of locomotive is by far the most important, and the distinctive features of its numerous varieties will require a more detailed enumeration than those to which we have already called attention. Fig. 5195 represents a locomotive of this kind constructed by Kitson, of Leeds, for one of the Indian lines. The mechanism, as usual, is inside, and the various parts are of wrought iron, with the exception of the piston-rod, which is of steel. The framing is double; the inner plates serve for the coupled wheels, and the outer for the pair of free wheels. The thickness of the inner plates is 1 in., that of the outer plates ¾ in. The journals of the coupled axles are 6 in. in diameter, and 9 in. in length, and rest in gun-metal bearings. The leading wheels have a lateral play of 1 in., and the journals have inclined bearings on Cortazzi's system. The suspension springs are calculated for a deflection of ¼ in. to the ton. Only those of the driving wheels may be regulated at pleasure. The weight is distributed as follows;—9 tons upon the leading wheels, and 19 equally divided upon the coupled wheels. The special appliances adapted to this engine are a smoke-consumer, consisting of a brick arch in the middle of the fire-box, and a deflector to make the air entering through the doorway pass under the arch; a Becker's anti-incrustator; Naylor's safety-valves; and a cylindrical spark-catcher placed in the smoke-box. The smoke and fire boxes are fixed with angle-iron to the barrel. The boiler is fed by two small Giffard's injectors fixed upon the footboard.

Fig. 5200 is an express locomotive of the Great Northern Railway, constructed by Fowler, of Leeds, according to Sturrock's plans. The coupled wheels are 7 ft. in diameter, upon which the weight is equally distributed. The leading wheels, and the six wheels of the tender, are 4 ft. in diameter. A distance of 17 ft. 9 in. separates the two extreme axles. The cylinders are 16 in., and the stroke is 24 in. There are 1000 ft. of heating surface, 112 ft. of which is contained in the fire-box; this latter has 19 ft. of grating. This engine is said to be capable of drawing twenty carriages over a line where the gradients are light at a speed of 60 miles an hour.

Fig. 5216 represents an engine by Borsig, of Berlin. It is a passenger engine, and possesses all the German features of framing and mechanism outside, and cranks upon the ends of the axles. An elegant box with sliding windows shelters the driver and fireman from the weather. The several parts of the mechanism are of cast steel, and of very small dimensions, according to Borsig's

custom. The weight upon the wheels is distributed as follows;—Upon the leading wheels 12·25, upon the middle wheels 11·75, and upon the trailing wheels 11·25 tons. The springs are 3 ft. 3 in. broad, and are composed in front of 9 plates, and behind of 12 plates, $\frac{1}{16}$ in. thick. The boiler is

5194.



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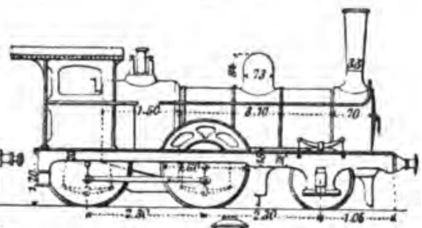

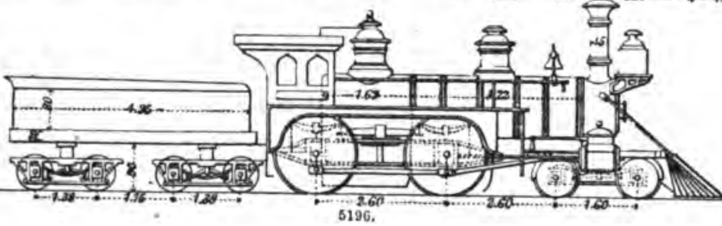

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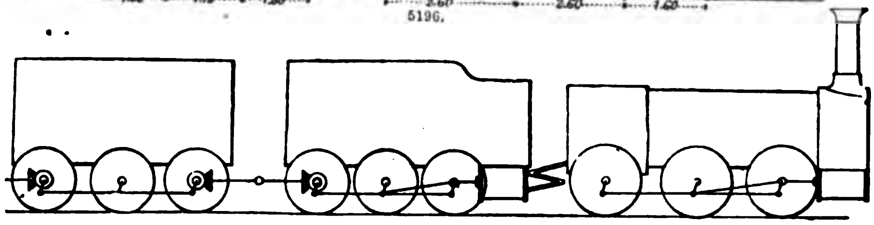

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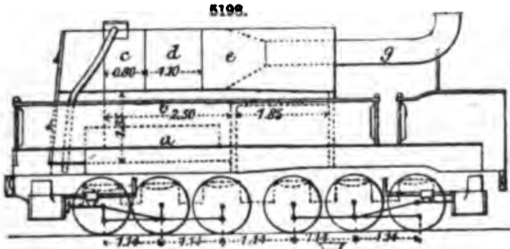

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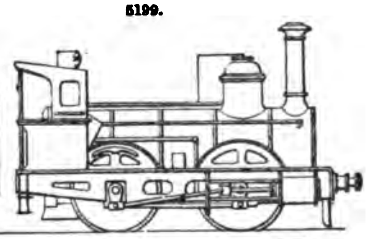

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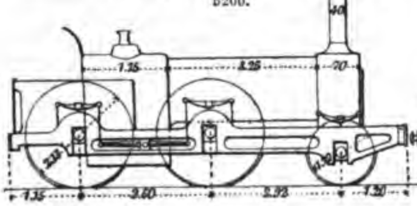

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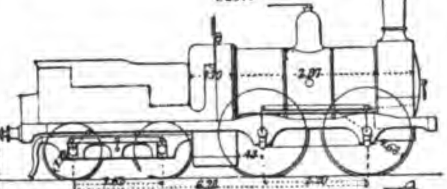

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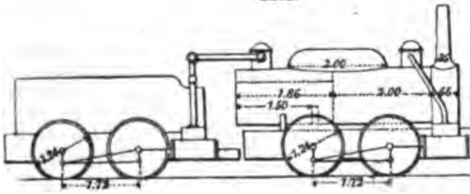

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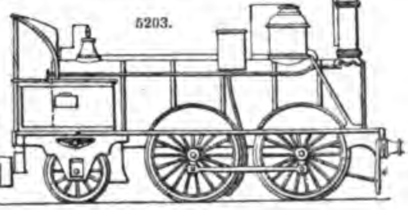
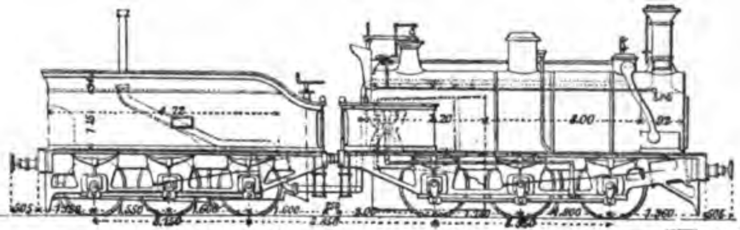


of plate iron $\frac{1}{16}$ in. thick, and contains 715 gallons of water, and 65 cub. ft. of steam. There are two gratings one above the other, the upper being 2 ft. 4 in., and the lower 5 ft. 7 in. from the crown of the fire-box. The trailing axle is beneath the higher grating, so that it is nearly beneath the

middle of the fire-box. The tender accompanying the engine is a type of the German tenders. It is of very large dimensions, and mounted upon six wheels. The framing is $\frac{5}{16}$-in. plate, and very elaborate in design.

Fig. 5217, a Belgian express locomotive. The main features of this engine are a large fire-box on Belpaire's system, a double framing, and internal mechanism of the English type, with lateral guides. The boiler contains 660 gallons of water, and 122 cub. ft. of steam. The distribution of the weight is 9 tons upon the leading axle, and 24 tons, equally divided, upon the middle and trailing axles.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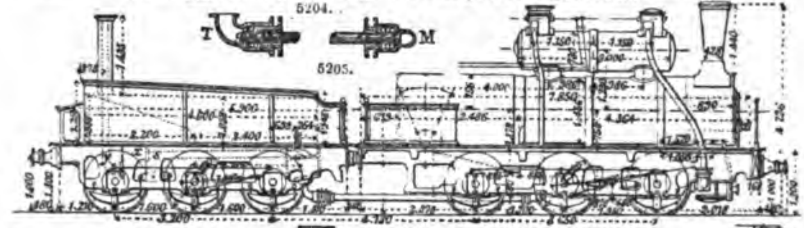
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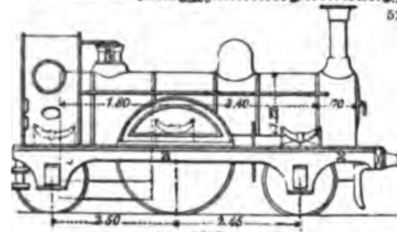
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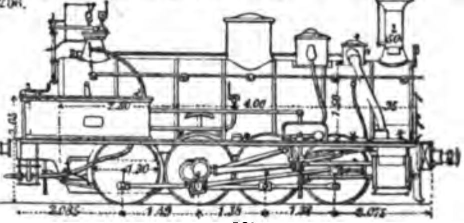
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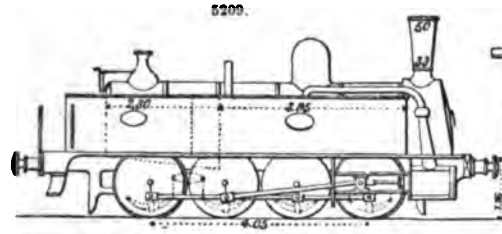

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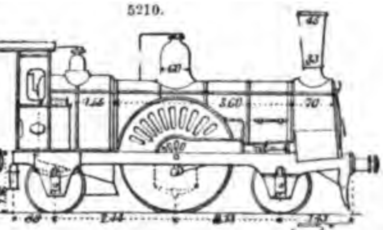


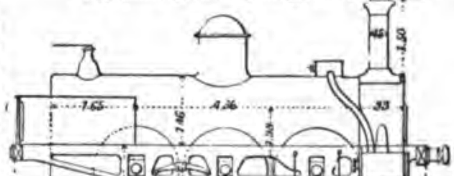
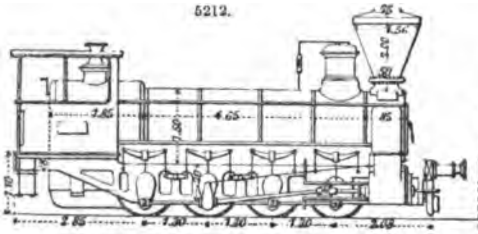

5211.

Fig. 5203 is a locomotive of the Lyons Railway, and is worthy of remark as the type of a class. It was originally constructed in 1851, but in 1867 it underwent considerable modifications, which have somewhat changed its character. An enumeration of the alterations effected will sufficiently explain the present nature of the engine. The tubular body or barrel was lengthened by 2 ft. 5 in., and consequently the fire-box placed farther back. The hind axle, with its supports, was changed, and the journals, which were originally inside, under the frame-plates, produced in a straight line, were brought to the outside, and the false outer framing added. The axle was also allowed a little play by means of Sharp's inclined planes. Kitson's system of changing the direction of the motion was adopted, and a Lechatellier steam-brake applied. Another noteworthy feature was the adoption of Thierry's system of consuming the smoke by an injection of steam, and introducing air through hollow stays. The boiler contains 660 gallons of water, and 52 cub. ft. of steam. The distribution of the weight is 19 tons, equally divided upon the leading and driving wheels, and 6¼ tons upon the trailing wheels.

The Cudworth engine, shown in Fig. 5201, was designed for passenger traffic between Charing

Cross and Greenwich, on the South Eastern Railway, and constructed at the Canada Works, Birkenhead. The engine is in this case really distinct from the tender, but both are mounted upon the same double and rigid framing. The mechanism is internal, and of the ordinary English type, with lateral guides. The wheels are between two frame-plates, and the coupled wheels of the engine proper have oil-boxes both on the outside and the inside. The distance of the driving axle from the fire-box is 1 ft. 5 in.

5212.



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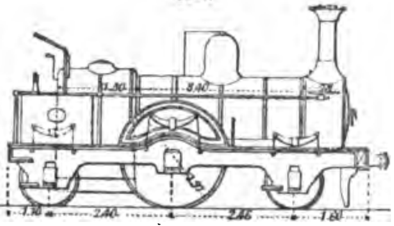

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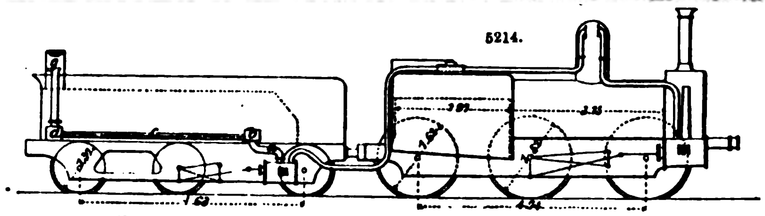

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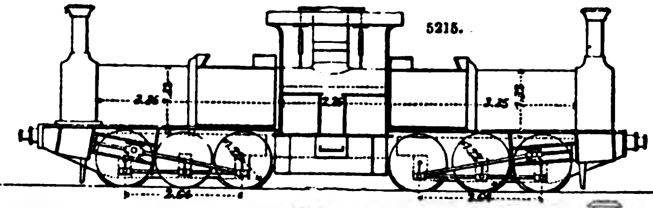

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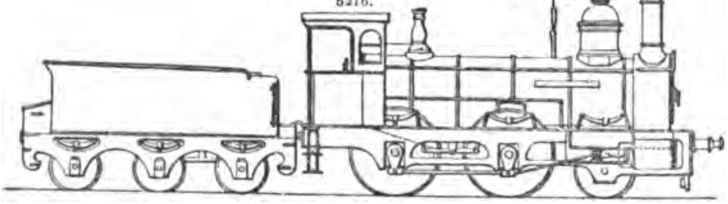

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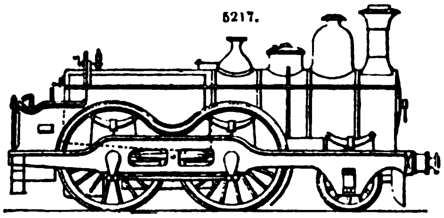

5218.

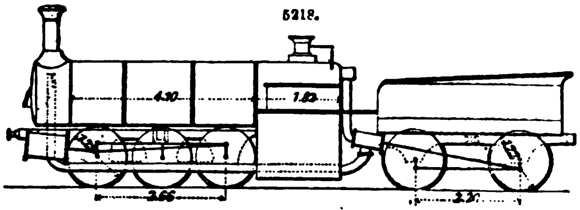

Fig. 5199 represents a passenger engine of the Baden Railway, which is marked by sharp gradients. This locomotive was built at the Graffenstaden Works, and may be taken as a specimen of the four-wheeled engines used in Germany. The cylinders are outside, and the mechanism of the distribution is between the wheels. The framing is also outside, as customary in Germany, and the frame-plates have ribs at the ends like a large I-iron. The following dimensions will be found interesting;—Volume of water in the boiler 3 cub. mètres = 660 gallons; pipes of the Giffard injector, 1¼ in. for the suction, and 1⅝ in. for the forcing; steam-ports 14 × 1¼ in., eduction 14 × 2⅜ in.; length of connecting rod, 7 ft. 11 in.; length of crank-pin 3⅝ in., diameter 3¼ in.; diameter of axle in the middle 6¼ in., at the bearings 8⅝ in.; length of journal, 5⅝ in. The springs are 2 ft. 10¼ in. in length, and made up of 11 plates 3½ × $\frac{7}{16}$ in. The weight of the engine, when in running condition, is equally distributed over the axles, each supporting nearly 13 tons.

Fig. 5196 is an American locomotive, by Grant, of Paterson, New Jersey. In form and construction this engine, which may be taken as a type of American locomotives, differs widely from those in use in Europe. It possesses a capacious fire-box and a powerful boiler, the plates of which

are $\frac{1}{16}$ in. thick. The fore part of the engine is supported upon a four-wheeled truck or *bogie*, and there are four coupled wheels. These wheels are of cast iron, with ties of Krupp's steel. The framing is inside, and very unlike anything of the kind now used in Europe, being similar to the framings constructed by Bury at the introduction of railways. The whole of the mechanism is outside, and similar in character to that of European locomotives. The boiler is fed by long and direct-stroke pumps, and not by Giffard's injectors. About 7½ tons of the weight is carried by the bogie, and about 20 tons equally divided by the coupled wheels. A large lamp is carried on the fore part of the engine, and over the boiler a bell is hung, which is rung on approaching stations. The sand-box is of the form of a dome, similar and symmetrical to the steam-reservoir placed above the fire-box. The fore part of the engine is provided with a cow-catcher, as usual in America. The tender is of very large dimensions, and is carried upon eight wheels, grouped in two trucks or bogies. A good deal of decorative art is expended upon American locomotives. The one represented in the figure has the whole of its body or barrel covered with a coating of highly-polished German silver.

Engines with uncoupled wheels.—It is the opinion of many engineers that locomotives provided with a single pair of driving wheels, the adhesive power of which can rarely exceed 2 tons, must sooner or later disappear altogether from active service, by reason of the continual increase of the weight of trains. This fact appears certain, if we except fast trains, the weight of which can never, without great risk, exceed 100 tons. Even with this load the train is almost ungovernable at a speed of 50 miles an hour, if it is necessary to pull it up suddenly. The coupling of wheels of large diameter is also attended with several practical difficulties, and we think that the express locomotive proper, with its single pair of driving wheels, will continue to hold its ground, demanding only improvements in those arrangements which give it stability. As types of this kind of engine we have selected three recent examples, which, as they were exhibited at Paris in 1867, may be taken as among the best of their class.

Fig. 5213 is from Stephenson, of Newcastle, and was built for service in Egypt. There is no novelty in this engine; the design and dimensions are those of the locomotives of fifteen years ago, and did the framing and boiler not evince a recent construction, it might be taken as an example of an engine that had seen long service. This fact shows that little advance has been made during the last few years either in the design or the execution of this class of engine. The mechanism is internal, and of the pure English type, with double lateral guides, the whole constructed to work easily. The frame-plates are double, one outside, the other between the wheels, stays being inserted wherever possible. The driving wheels have on each side a double grease-box of bronze, and a double suspension spring; all the springs are capable of being regulated at pleasure. The barrel of the boiler is formed of three cylinders, held together by hoops on the outside, and rolled circularly, like certain kinds of tire for railway wheels. The construction, without longitudinal riveting, was rendered simple by the introduction of the rolling mill, a system that is carried out at Lowmoor. The rivets used in Stephenson's engine have hemispherical heads, and all the rivetings are double. The boiler is fed by long, direct-stroke pumps, on the old system, instead of Giffard's injectors. It contains 556 gallons of water, and 50 cub. ft. of steam, inclusive of the contents of the dome.

Fig. 5207 is one of the Lilleshall Company's locomotives specially designed for service in India. It is a very pretty specimen of its kind, and is another good illustration of the pure English type. The mechanism is internal, with double lateral guides for the cross-heads of the pistons, but the cylinders have a slight upward inclination. The framing is double; the inner plates carry the oil-boxes of the driving axle, the outer hold the end uncoupled wheels, as shown in the figure. The springs are all independent, and only those of the driving wheels are capable of being tightened at pleasure. The axles and the tires of the wheels are of steel. The slide-valve is of the straight form known as Allen's. The fire-box contains a brick arched roof, and an air deflector, to consume the smoke. The boiler is provided with self-acting lubrificators, and with safety-valves on Ramsbottom's system, and the general type of the engine is in accordance with that engineer's ideas. There is a complete plate-iron box over the foot-plate, to protect the driver.

Fig. 5210 is an express locomotive of the Great Eastern Railway, and was built at Creusot, in France, from J. Sinclair's designs. The framing is double, the outer plate carries the small end wheels, and the inner embraces the driving wheels. The cylinders are outside the wheels, and between the two frame-plates, and have an inclination of $\frac{1}{17}$. The tender accompanying this engine is supported upon six wheels; it contains 8¼ tons of water and 2½ tons of coal, and its weight, when in running condition, is about 24 tons.

Four-cylinder Locomotives.—Though these engines differ from each other somewhat in design, they must all be regarded as essentially two distinct engines, supported upon two united but distinct framings, the latter, however, partaking more of the nature of an independent truck or bogie. The former of these, which contains the boiler, may be called the engine proper, and the latter the tender-engine. Each type differs from the others in the mode of communicating the steam, and in the special purpose to be effected. But in every case the addition of the mechanism to the tender is designed to furnish promptly an auxiliary motor, the use of which may be intermittent and occasional, as, for instance, to make up lost time, or to ascend a sharp gradient. To give a correct notion of the development of this kind of locomotive, we must describe the systems of Verpilleux, Cernuschi, Flachat, and Sturrock.

Fig. 5202 represents one of Verpilleux's engines which were in use upon sharp gradients some years ago. Verpilleux first introduced his engine in 1842. The two trucks rest each upon four coupled wheels, and the mechanism is external as in the small locomotives of that date. To increase the boiler power of the engine proper, a reservoir in the form of a half-cylindrical box was placed upon the barrel, which appliance was, however, found not to possess sufficient solidity, as the train stopped four times during the ascent of the gradient, as sufficient quantity of steam accumulated to keep up the speed of the engine. The steam was conducted from the boiler to the cylinders of the tender through pipes over the head of the driver. We do not remember how the

steam was discharged from the cylinders of the tender, but we think it was allowed to escape directly into the air through a single vertical tube. Verpilleux's locomotive had cast-iron wheels with wrought-iron tires. The framing was of wood. The form of the boiler was cylindrical, and it contained a fire-box of the same form.

Fig. 5197 represents a system suggested by Cernuschi which never got beyond the state of a project, though it made considerable stir in its day. Here again, as in Verpilleux's first plan, the steam is brought from the boiler into a couple of auxiliary cylinders in the tender. But besides this, Cernuschi wished to utilize the adhesion of the trucks or carriages of the whole train, if needful, by transmitting the motive power to them by means of gearing. Cernuschi's system is worthy of careful consideration. To convey the steam from the boiler to the cylinders of the tender, he employs a number of small tubes which, being arranged spirally, yield readily to inflection. The mechanism is external both upon the engine and the tender; the boiler is of great power, having a large number of tubes in a long barrel, the diameter of which is 4 ft. 11 in., and a very capacious fire-box supported in the middle by one of the pairs of wheels as in the most recent models of engines, a fact of this date, 1856, worthy of attention.

At about the same time Flachat proposed for the Alpine railway a locomotive in which, not only the tender, but several of the carriages of the train might occasionally be rendered motors, by the addition of cylinders supplied with steam from the very powerful boiler of the engine proper. The project was, however, never carried out.

Fig. 5214 represents Sturrock's engine. This eminent engineer of the Great Northern Railway took out a patent in France in 1864, reproducing his English patent, and several goods engines underwent alterations under his direction at the works at Doncaster. The tender in this case received a motion precisely similar to that of the engine, the exhaust being turned into a tubular condenser in the water-tank. The only essential change effected in the engine itself was the lengthening of the fire-box, and the addition of a special steam intake. The main features of this locomotive are;—The cylinders are inside, and the valve gear is also inside between the cylinders. The framings are fixed and double, one outside and the other inside, in accordance with Gooche's original plan, generally adopted by Sturrock. The tender has a single framing which is outside the wheels. The mechanism is internal, but horizontal. The whole is heavy as usual on the Great Northern Railway. The essential features of Sturrock's engine are, the conveyance of steam to the tender through a long pipe yielding readily to flection by reason of its length of upwards of 22 ft., and the steam exhaust, which is effected in a real tubular condenser placed in the water-tank. *a* is the conduit through which the steam is taken; *b* and *d*, two chambers, between which is a double row of condensing tubes, 15 in number. The uncondensed steam escapes into the air through the pipe upon the chamber *d*. The end of this pipe is provided with a cylindrical cover, of larger diameter than the pipe, and perforated on the top *g*, to prevent the water from being ejected with the steam and to cause it to fall back into the tank. The water produced by condensation in the tubes appears to have no other outlet. There are said to be a large number of these engines in use upon the Great Northern Railway, where they are employed to draw heavy trains up the gradients without any reduction of speed.

Fig. 5218, Fairlie's engine with steam-tender. This variety of locomotive is the counterpart of Sturrock's. It is characterized by a particular arrangement of the mechanism, the large barrel of the boiler and the grouping of the wheels on two bogies to enable the engine to get round sharp curves. For the same reason neither the boiler nor the water-tank of the tender is fixed to the framing in the usual way. These framings, with the mechanism they carry and the wheels, are arranged as bogies susceptible of lateral displacement on curves, and the boiler and the water-tank are mounted so as to give a little lateral play to the framing beneath. The other features of the Fairlie type are the long boiler tubes, 13 ft. 5 in.; a vertical water-space in the middle of the fire-box; outside cylinders slightly inclined, and inside valve mechanism; single framings, and suspension springs underneath the axles. Steam is conveyed to the tender by a short kneed tube starting from the fore part of the fire-box. The exhaust is, as usual, turned into the chimney through a long pipe passing beneath the boiler, and yielding to inflection by reason of its length, like Sturrock's steam-pipe.

Fig. 5206 is an engine of the Great Central Railway of Belgium, built at the company's works at Louvain according to the designs of Maurice Urban, the chief engineer. This engine, which is called Verpilleux's in acknowledgment of the French invention, is capable of drawing trains of 245 tons weight, exclusive of the engine, at a speed of 12 miles an hour upon a line where the curves have a radius of only 1640 ft., and the gradients are from one in a hundred to one in sixty, over a distance of 17 miles. By reason of its powerful boiler, it is capable of working continuously with its four cylinders. The following are its principal features;—A long furnace on Belpaire's system with a roof fixed by means of stays instead of the usual armatures; an inclined grating with very small bars for the purpose of burning small coal; the fire-box rests upon the middle of the trailing axle, and like the furnace widens out forwards. The chimney is of the form of an inverted cone; a barrel nearly filled with tubes, and surmounted, as in Verpilleux's engine, with a cylindrical reservoir. The driving mechanism is inside, the framing single and outside the wheels. The springs are beneath the axles, with balance-rods from the leading to the driving wheels. The tender has six wheels and a framing similar to that of the engine. Steam is conveyed through a pipe passing beneath the boiler, and jointed at its two ends by the mechanism shown in Fig. 5205. On the side of the engine M, the pipe *o o* works with a steam-tight joint in a stuffing box, in three vulcanized india-rubber rings *a a a*. On the side of the tender T, the pipe is provided with a collar working between two similar rings *g g*. The exhaust steam from the cylinders of the tender is conveyed beneath the water-tank by two pipes *s s* into a common box *x*, from which a pipe *z* leads to the open air. The following dimensions are worthy of notice:—Inclined grating, 7 ft. 5 in. × 3 ft. 5 in. Volume of steam-reservoir, 45·5 cub. ft. Diameter of the journal of the driving axle, 10¼ in. Distance of the cylinders apart, in the engine 2 ft. 2¼ in., in the tender

2 ft. 4½ in. Length of the connecting rods, in the engine 5 ft. 9¼ in., in the tender 3 ft. 11½ in. Diameter of piston-rod, 2¼ in.

The Eastern Railway of France possess engines constructed at the Graffenstaden Works from designs furnished by their chief engineer Vuillemin, who has followed out Sturrock's system. Fig. 5204 represents one of these engines, which are intended for service upon certain sections of the line exceptionally distinguished by rising and falling gradients. The inside mechanism is arranged nearly in the same way as Sturrock's, with a single framing outside the wheels, and coupling cranks upon the ends of the axles. The wheels of the tender are a little smaller than those of the engine. The boiler is a very powerful one, with inclined grating, short tubes, and a large heating surface direct from the fire-box. The latter is supported near the middle by the trailing wheels, and is provided with two doors and a water-space descending freely from the roof. Steam is conveyed to the cylinders of the engine through a long, free, kneed pipe, as in Sturrock's system. But the exhaust is effected through a pipe communicating directly with the open air. The boiler is of steel plate, and the various pieces of the mechanism are of cast steel. One of these locomotives is capable, with the assistance of the tender, of easily dragging 575 tons gross at a speed of 16 miles an hour up a gradient of $\frac{1}{100}$, sometimes with curves. The distribution of the weight of the engine over the wheels is such as to give it remarkable stability.

If now we compare the seven preceding types, we shall find that, with a common principle, each differs in the arrangement of the mechanism.

1. Verpilleux, Cernuschi, and Fairlie have outside mechanism; Sturrock, Urban, and the Eastern Company prefer inside mechanism, but with a framing outside the wheels, and coupling cranks upon the ends of the axles.

2. With the exception of Verpilleux, who used only four wheels, with a fixed distance 5 ft. 7½ in. apart, all the other types have six wheels, excepting Fairlie's tender, which has only four wheels.

3. Sturrock and the Eastern Company have assigned to the tender wheels a little smaller than those of the engine.

4. In all the systems the capability of the boiler has been increased, with the exception of Urban's, with a view to furnish steam to the tender for short periods only. Verpilleux and Urban have enlarged the steam-space.

5. Each system has its own mode of conveying the steam to and from the cylinders. Sturrock has a long pipe, flexible of itself, and exhausts in a tubular condenser. Fairlie has a short kneed pipe, and exhausts in the chimney through a long pipe, like Sturrock's conveying pipe. The Eastern Company have borrowed Sturrock's pipe, but they exhaust directly into the open air without condensation. Urban has a pipe jointed with elastic rings in a stuffing box. Cernuschi effects communication between engine and tender by means of spirals.

The engines which we have described above are known as steam-tender engines; but there are others employed for heavy traffic, chiefly upon Continental lines, in which the four cylinders are placed in the engine itself. These locomotives are, of course, very large and very heavy. We shall confine ourselves to a description of two of these, one in use upon the Northern Railway of France, the other constructed by James Cross, of St. Helen's, from Fairlie's designs, for the Southern and Western Railway of Queensland. The following are the fundamental characteristics of the French four-cylinder locomotive, Fig. 5198;—Beneath a rigid framing there are twelve wheels arranged in two independent groups, each having its own driving mechanism. Upon the single and inside framing there is first the water-tank *a*, and above this the boiler *b*, the shallow but long and wide fire-box *c* of which extends laterally beyond the framing and the wheels. A superheater *d* is placed above the boiler, the tubes of which superheater are 2 ft. 7½ in. in length, 3 in. in outer diameter, and have 161 sq. ft. of surface. Then comes a second tubular chamber *e*, having the same number of tubes, of the same diameter, but 3 ft. 7 in. in length, and having 215 sq. ft. of surface. These are for the purpose of heating the feed-water, which is forced into the boiler by pumps. A small Giffard's injector is provided in addition to these pumps, to work while standing still. In consequence of the great height of the engine, the chimney has to be placed horizontally, as shown in the figure. Experiments have shown that with the steam-blast the chimney draws as well in this as in the vertical position. It will be remarked that the whole of the mechanism is outside, and that the two groups of wheels with their separate mechanism are quite independent of each other. The fore and after axles of each group are susceptible of a little end play to enable such a great length of coupled wheels to get round curves.

Fairlie's engine is represented in Fig. 5215. Its main features are a rectangular fire-box placed between two symmetrical barrels, having altogether a length of 37 ft. 8 in., including the smoke-boxes, which boxes are surmounted by a common chimney provided with a spark-catcher, wheels and driving mechanism forming two independent groups on each side of the fire-boxes. These groups, with their framing, form a kind of bogie, and pipes capable of side inflections for conveying steam to the cylinders, and from the cylinders to the chimney.

See Adhesion. Boilers. Brake. Details of Engines. Dynamometer Car.

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LOOM. Fr., *Métier*; Ger., *Webestuhl*; Ital., *Telajo*; Span., *Telar*. See Weaving Machinery.

LUG. Fr., *Oreille, Tasseau*; Ger., *Krone, Angussform*; Ital., *Orrecchio*; Span., *Halare*.

A *lug* in machinery is any projecting piece to communicate motion; especially a short flange by or to which something is fastened. A projecting piece upon a founder's flask or mould is also called a lug.

MACHINE. Fr., *Machine*; Ger., *Maschine*; Ital., *Macchina*; Span., *Máquina*.

In general any body or assemblage of bodies used to transmit and modify force and motion, as a lever or a pulley, is a machine; but the word is applied specially to a construction more or less complete, consisting of a combination of moving parts or simple mechanical elements, as wheels or cams, with their supports and connecting framework, calculated to receive force and motion from a prime-mover or from another machine, and transmit, modify, and apply them to the production of some desired mechanical effect or work. The term machine is most commonly applied to such pieces of mechanism as are used in the industrial arts for mechanically shaping, dressing, and combining materials for various purposes, as in the manufacture of cloth, and so on.

When the effect is chemical or other than mechanical, the contrivance is usually denominated an apparatus, not a machine, as a bleaching apparatus.

Many large, powerful, or specially important pieces of mechanism are called engines, as a steam-engine, a fire-engine. Unfortunately, however, there is no well-settled distinction between the terms engine and machine among practical men.

MACHINE TOOLS.

Those machines used in the finishing and fitting of machinery, after the more important operations of either forging or casting the rough material have been effected, are collectively designated as machine tools.

The objects machine tools are designed to effect are the cutting or grinding away of surplus material so as to produce true dimensions; removing the excess that has to be left in casting or forging, in consequence of the expanded condition of the material, or for other reasons that prevent accuracy; and in certain cases spinning the material into shape by contact with plain revolving surfaces, each of these operations being essentially aided by the ease with which the material operated upon can be moved to, in, or from the machine.

Although machine tools form an essential portion of the equipment in any machine shop, the circumstances under which they have to be designed are so various as to prevent the adoption of but very few standard tools, and the complex nature of their action is indicated by the diversity shown in their construction.

In most examples of machine tools the relative motion of the tools and the work or material operated upon results from three component motions usually at right angles to each other, or of two out of those three; they are the cutting motion, the traversing or transverse feed-motion, and the advancing feed-motion, the first two taking place parallel to the face of the work, and the third in a direction normal to it. The cutting motion is the most rapid of the three, being that by which the tool acts on the face of the work, leaving a narrow strip or band from which a portion of the material has been pared or scraped away. In many instances the cutting portion is effected by a motion of the work, the tool remaining fixed, and such is particularly the case in turning and screw-cutting lathes, and in many planing machines. There are other operations in which the cut is made by a motion of the tool, such are drilling, boring, shaping, and slotting. The speed of cutting tools is limited by the heat produced by their action, and this heat must never be so great as to affect the temper of the steel. Hence it is less, the harder the material of the work. White cast iron is usually cut at a speed of about 5 ft. a minute, steel and grey cast iron 10 to 20 ft., wrought iron 18 to 25 ft., brass 50 to 100 ft., and wood from 3000 to 10,000 ft. a minute. The transverse feed-motion takes place parallel to the face of the work and at right angles to the cutting motion; it is that motion by which the tool is made to shift its position relatively to the work, so as to make a series of parallel cuts, side by side, leaving a series of parallel strips or bands, which compose a surface of any required extent. This motion is sometimes continuous and sometimes intermittent. The rate at which the traversing motion takes place in paring a continuous surface depends on the breadth of the cut, which in iron ranges from ·1 to ·01 in. In screw-cutting the traverse at each revolution is equal to the pitch of the screw. The advancing feed-motion is that by which, after a certain depth of material has been cut away from the face of the work, the tool is advanced to cut away an additional depth. This is very frequently an intermittent motion, and in turning and planing machines it is usually an adjustment made from time to time by hand. Its extent at each adjustment is equal to the depth of the cut, which in iron ranges from the smallest appreciable quantity up to ·5 in. in ordinary cases. The cutting action of the tools may be conveniently divided into cylindrical cutting for circular forms, cutting in right lines for planes, and irregular cutting where the forms have neither true curves nor right lines.

Lathes.—The leading principle of the lathe is the rotation of material in contact with cutting tools. The principal parts of a machine-lathe are shown in Figs. 5219, 5220, which are of a standard lathe by William Muir and Co. of Manchester. J is the driving pulley; *k*, fast head-stock; *l*, reversing gear; *m*, driver-chuck; *n*, mandrel; O, poppet-head; *q*, back-stay and stepblock.

a a are the standards, *b b* the lathe-bed made truly plane and horizontal; the top of the lathe-bed is cast with the flanges 1, 2, flange 1 projecting more than flange 2, so as to afford protection to the screw and adjustment gear. The recess between the brackets is just sufficient to allow the clamp of the poppet-head or movable head-stock to pass; *c*, the saddle, the parts *d d* of which project to give it bearing and prevent rocking; *e*, top-slide movable on the saddle for adjustment; *f*, the swivel or tool-slide; this can be turned to the angle necessary for the work, and for surfacing up to the full capacity of the lathe; it is fixed by means of two screw-bolts *g*; *h h*, the screw, gearing into a half nut and traversing the saddle; the nut is thrown into and out of gear by the handle *i*.

The screw is by some machinists placed in the body of the bed.

Fig. 5221 is a section of the releasing motion to the tool-slide, Fig. 5222 an end view of the head-stock showing the reversing motion, and Fig. 5223 the mandrel with steel bushes, cone, and

iron; from 2 to 32 threads to the inch can be cut with the usual set of gears. All nuts, screws, and wrenches are case-hardened. The carriage is heavy, and has long bearings carefully fitted to the slides by scraping; it is jibbed its whole length to outside of the bed, and has an elevating tool-rest and automatic cross-feed.

The lathe-spindle of a machine-lathe can either be fitted with chucks of different sorts; being discs provided with holes, pins, and other means of holding the work, and causing it to rotate along with the lathe-spindle; or with a mandrel or cylindrical continuation of the spindle, on which wheels and pulleys, and other pieces of work having eyes in their centres, can be keyed for the purpose of being turned.

A chuck in the form of a large circular disc is called a face-plate. Some lathes have face-plates on both spindles; and then the two spindles are driven at the same speed, by means of two pinions on one shaft, gearing with teeth on the rims of the face-plates.

The greatest radius of the work which can be turned in a given lathe is limited by the height of the axis of rotation above the bed; and the lathe is described according to that height.

The tool-holder is adjusted so that the point or cutting part of the tool is exactly in a horizontal plane traversing the axis of rotation. The direction of rotation is such that the surface of the work moves downwards at the point of the tool, which accordingly cuts upwards.

The screws and nuts, or the pinions and racks, by which the traversing motions of the tool-holder are produced, are driven from the lathe-spindle through trains containing change-wheels; and by means of these the velocity-ratio and directional-relation of the cutting motion and of the traversing motion can be adjusted so as to produce the required resultant or aggregate relative motion.

When the word traversing is used without qualification, it generally means that the tool traverses in a direction parallel to the axis of the lathe, so as to turn a cylindrical surface. When the tool is made to move in the direction of a radius perpendicular to the axis, it turns a plane surface, and the process is called surfacing. This is very often the means used of making a plane approximately, previous to correcting it by scraping. By combining those two motions, so as to make the tool traverse in a straight line cutting the axis obliquely, a conical surface is turned. When the point of the tool is made to traverse in a circle, one diameter of which coincides with the axis, a spherical surface is turned.

All these operations are examples of circular turning in which the point of the tool describes, relatively to the work, a circle about the axis, if the traversing motion be neglected, or a helix or spiral of a pitch equal to the traverse a revolution, if this component of the motion be taken into account. In eccentric turning, the point is made to describe, relatively to the work, paths of various other kinds, such as eccentric circles, ellipses, epicycloids, and arbitrary curves of various sorts. Such aggregate paths are produced, sometimes by epicyclic trains carried by the chuck which holds the work, as in the eccentric chuck, elliptic chuck, and geometric chuck; sometimes by the action of cams or shaper-plates on the tool-holder. The operation of cutting screws is performed in a lathe; the work rotates, and the tool-holder is made to traverse longitudinally by means of the guide-screw. The nut by means of which the guide-screw drives the saddle is a clasp-nut, which can be thrown into or out of gear with the guide-screw when required. The guide-screw is made with great care and precision. An ordinary value of its pitch is half an inch. The velocity-ratio and directional-relation of the motions of the guide-screw and of the lathe-spindle are adjusted by means of change-wheels to the pitch and direction of the screw to be cut, according to the principle that, $\frac{\text{speed of rotation of guide-screw}}{\text{speed of rotation of lathe-spindle}} = \frac{\text{pitch of new screw}}{\text{pitch of guide-screw}}$; or the direction, right or left handed, of the new screw, is similar or contrary to that of the guide-screw, according as the directions of rotation of the guide-screw and of the lathe-spindle are similar or contrary.

Drilling and Boring Machines.—Drilling, as an operation in metal cutting, differs from any other, in the fact that the cutting edges support and guide themselves, during their action, and are not held by slides or spindles. The point of the drill, being in advance of the edges, forms an axis that holds and guides the lips or wings, and enables us to drill holes, almost anywhere in a piece, with only a revolving spindle having a feed movement.

Drilling, although it has many other objects, is mainly directed to connecting and joining together the parts of machinery, which constitutes a great share of what is termed fitting. We find drilling machines are needed in nearly the same proportion as lathes or planing machines, but their arrangement, although directed mainly to drilling parallel holes, at various places in the work, is more varied than that of other machines.

In ordinary practice they can be divided into column, or self-contained machines, radial, suspended, horizontal, and angular drilling machines. The essential parts are shown in the double geared drilling machine of Wm. Muir and Co., Manchester, Fig. 5226. They consist of a revolving spindle, with a forward feeding movement, and changes of speed to suit the various sizes of the holes to be drilled, and with a firm support for the material, having a vertical adjustment to and from the spindle, and a compound adjustment horizontally.

Fig. 5227 is of a well-designed 20-in. drilling machine, by Wm. B. Bement and Son, Philadelphia. The spindle is fed down by means of the tangent-wheel and worm at *a*, operated by the vertical shaft *b*. The worm is disengaged from the tangent-wheel by partially turning the rod *c*, which allows the spindle to be moved rapidly up or down by means of the handle *d*. The power-feed is engaged and disengaged by the clutch *e*, operated through the handle *f*, and a rod passing centrally through the shaft *b*. There are eight changes of speed, including the changes of the back-gearing, which is thrown in and out by the handle *g*. The cones are locked by a stop operated by the handle *h* passing through the shaft to the cones. The table *i*, and swing brackets *k*, are adjusted vertically by a screw set in a recess in the front of the main column, and turned by a handle fitting on to the shaft at *j*.

The driving gearing is encased in the main frame, at *m*, to prevent danger and decrease noise.

A powerful radial drilling machine, with self-contained driving apparatus, made by Wm. Muir

and Co., is shown in Fig. 5228. It consists of an upright frame, bolted to a strong base-plate, with a slide *s*, that can be raised or lowered. This slide has a radial arm *r* fixed on centres, projecting horizontally from a strong hollow standard, and carrying the tool or drill, which is driven by an arrangement known as a shifting train, in order that the position of the drill may be shifted to various parts of the work. Power is transmitted from the main driver to the driving apparatus *a*, and by a belt to the coned pulley *x*. Thence by a mitre-pinion at the end of the shaft, to which the coned pulley is attached, to the vertical shaft that drives the shifting train.

5229.

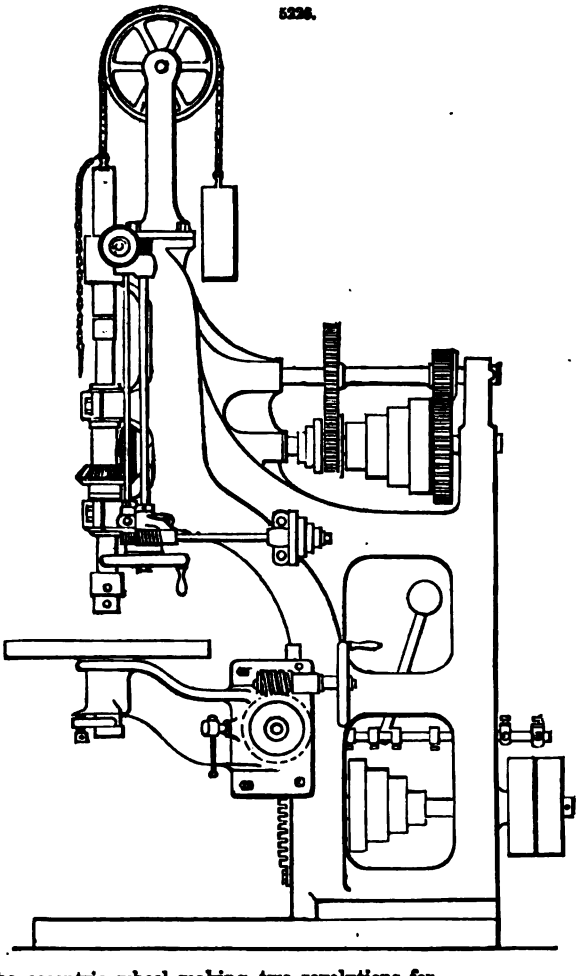
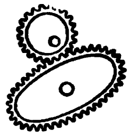


Fig. 5229 is of Sharp, Stewart, and Co.'s double traversing drilling machine.

The machine rests on stands, and has a bed on which two adjustable tables and two traversing drilling head-stocks are mounted, with their gearing, which receives motion from straps, by which the two head-stocks are driven independently of each other. The revolving motion of the cutting tools is communicated from shafts through ranges of toothed wheels, variations of speed to suit different sorts of work being obtained by cone-pulleys, driven from corresponding pulleys on shafts above.

The reciprocating and feed motions are communicated from the shafts by cone-pulleys and straps, thus the rate of traverse and feed can be adapted to various kinds of work. The range of reciprocation is governed by fixing the pins of two connecting rods in the required positions in slots formed on the upper surface of two elliptical toothed wheels, and the velocity of horizontal traverse of the head-stocks is rendered nearly uniform throughout the entire stroke by a combination of elliptical toothed wheels with eccentric toothed wheels, Fig. 5230; the eccentric wheel making two revolutions for one of the elliptical wheel.

5230.



The feed-motion is transmitted from the elliptical wheels to the drill-spindle by ranges of gearing, including friction-plates. The downward feed of the tools is made at the end of the reciprocation, at which time the head-stocks are travelling at their minimum velocity.

To obtain great steadiness of the drills, the bosses in which the drill-spindles slide are made of considerable strength, and the drills are as short as the work will admit of; so that while drilling to any ordinary depth the ends of the spindles do not protrude far below the bottoms of their sockets, and nearly the same distance is preserved from the point of support to the cutting point during the entire process. Conical bearings, with tightening nuts, are adopted, so as to allow for wear and tear of the parts.

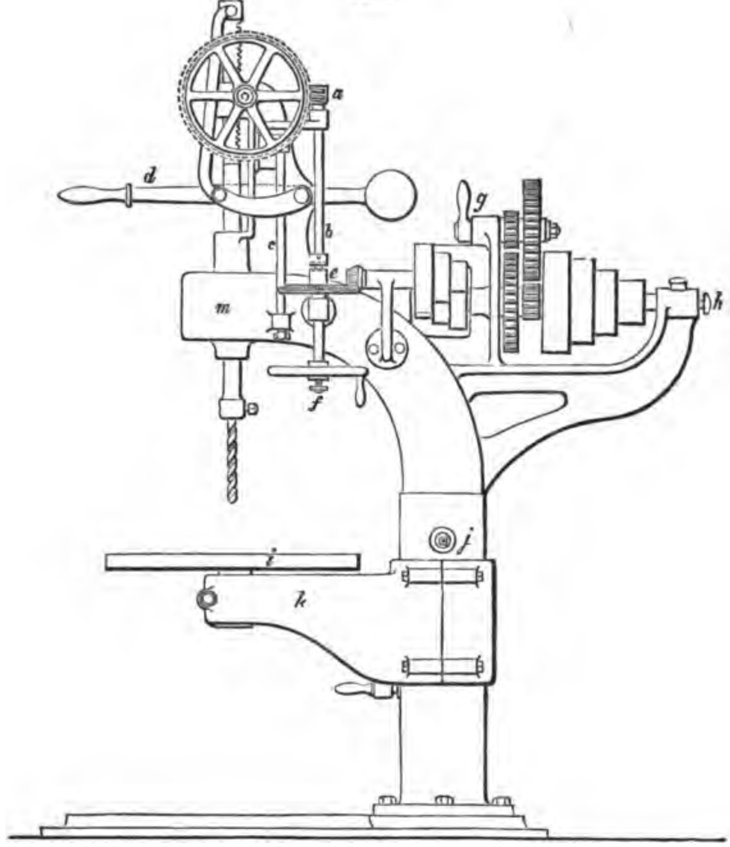
In order to ensure standard dimensions in the work corresponding to the dimensions of the tools, it is necessary for the centre lines of the cutters to be perfectly in line with the axes of the drill-spindles; and to effect this adjustment accurately, the sockets in the drill-spindles should be made conical, and screwed at the bottoms, the drills having corresponding screws and conical fitting parts; cotters also will answer the same purpose as screws to draw the drills tight up in their sockets.

The drills are not of the form generally used in other machines, but have their cutting parts at the circumference only. In order to preserve uninjured the standard dimensions of work, it is in practice found desirable to rough out the work previously to nearly the size intended, by drills, which may be sharpened from time to time when necessary during the progress of the work, and then to finish it by standard rose bits, which will last for a great number of pieces of work without any perceptible alteration in their dimensions.

If a cross traverse is required, it can be given by a self-acting motion applied to the transverse

slides on the tables holding the work, in which case the longitudinal traverse of the drill head-stocks would be suspended. If other than straight grooves are required, they may be obtained by combina-

5227.



tions of the longitudinal traverse of the head-stocks and the cross traverse of the tables, both going on at the same time. If circular grooves, or portions of them, are required, they may be obtained by the use of self-acting revolving tables, in connection with the ordinary tables for holding the work.

The numerous purposes to which these machines may be applied will readily suggest themselves; for instance, one drill may be slotting or surfacing, and the other drilling plain holes; or both may be drilling plain holes, slotting or surfacing, as required. They have been used for such work as cutting cotter-holes in locomotive connecting rods—both ends at the same time, cotter-holes in connecting-rod straps, in pistons, piston-rods, and cross-heads; for cutting key grooves in shafts, for cutting oil-cups and joints of motion work out of the solid, and oil-ways in bearing brasses; and for various other similar purposes in connection with locomotive engine building and engineering tool-making.

The great advantage of these machines is perhaps best seen in the difficult and tedious operation of cutting slots and cotter-holes, and that when once started requires so little attention that an operative with an assistant can with ease look after two double machines.

It is important to observe further, that in contrast with most other workshop tools, no time is lost during the execution of a piece of work by this machine, but the work progresses without intermission from the commencement to the completion.

Boring is quite different from drilling, and might be called internal turning, the operation being almost identical. Boring is, however, the most difficult to do, for the action of the tools cannot be watched as in turning, being as a rule out of sight; the dimensions are more difficult to gauge, while cored or interior surfaces are both harder and more irregular than outside surfaces.

Lathes are the best boring machines for any work that can be fastened on the carriage. Machines with a fixed bed are extensively used, and answer well for ordinary purposes; but, as the character of the hole is dependent upon the bearings of the boring bar, and affected by its being sprung, or out of truth, the safest plan for accurate boring is to revolve the bar upon centres, and if possible without other supports.

In boring on machine frames this is inconvenient and unnecessary, but for piston-cylinders, cylindrical valves, seats, and such purposes, this plan of boring is best.

The tendency at this time is to cast machine frames in one piece, with cored sections. The

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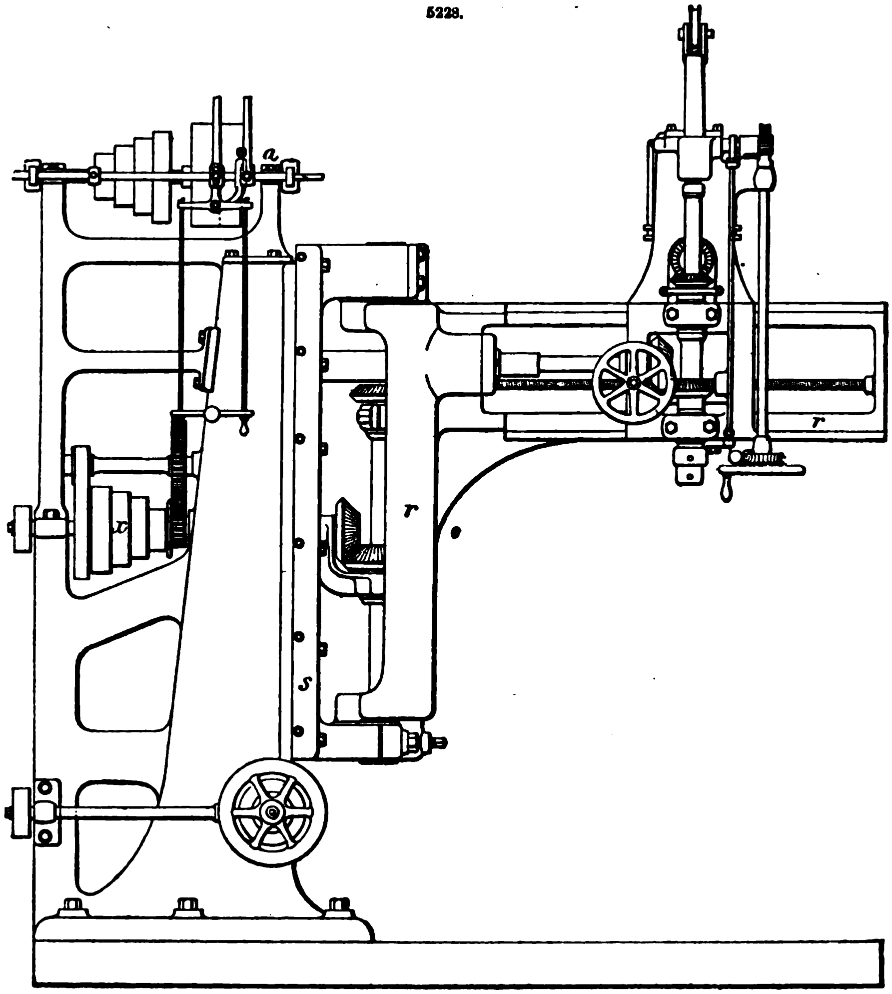
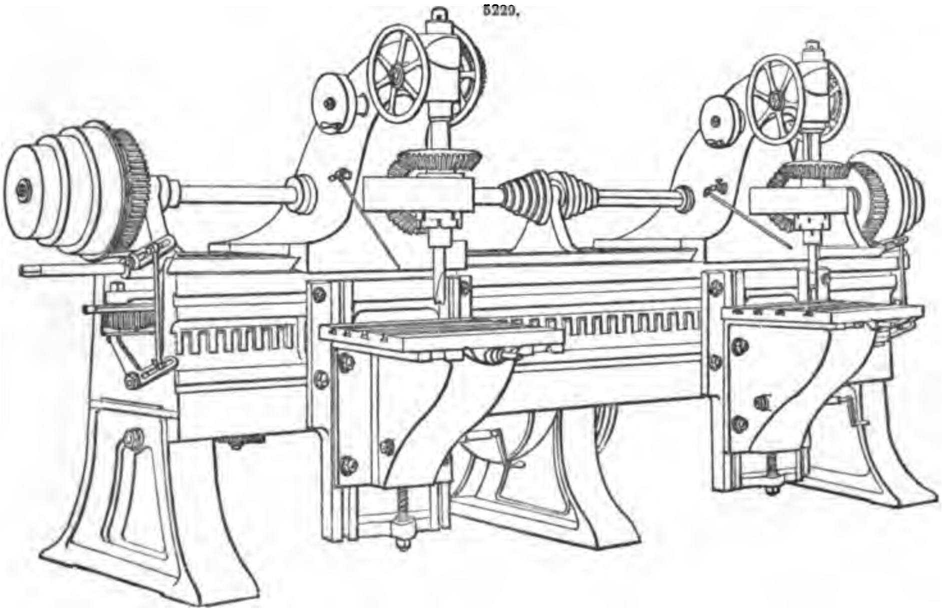


5229.



bearings for shafts have to be bored in various parts of the frame, and calls for the exercise of ingenuity and judgment on the part of the workman in the arrangement to support and drive boring bars. Experience has, however, demonstrated that it is better and cheaper to cast the bearings solid in the frames. A heavy solid plate placed under a strong suspended drilling spindle, and a bracket with level gear to change for horizontal boring, makes an outfit that will bore almost any hole about machine frames.

Planing Machines.—The term planing is or may be applied to all tools with rectilinear movement, for producing planes or other work performed in straight lines.

Shaping and slotting machines belong to the same class, and with the regular planing machine rank next to lathes in their use and importance, as implements in machine manufacture.

Machines for planing can be divided into two classes, those wherein the material is moved in combination with the cutting tools, and those that have only movement of the tools. In practice we find the rather anomalous arrangement of having the cutting movement with the tools for the lightest and for the heaviest classes of work, and the cutting movement given to the material for pieces of medium weight. There are advantages gained in either plan, the preponderance being for average work, in favour of moving the material on a platen beneath the tools.

Planing machines cut straight surfaces of all kinds; and are used especially for the cutting of plane surfaces to a certain degree of approximation; that is, the longitudinal straightness of the surface is perfect, but the transverse straightness is approximate.

The cutting action is effected by a longitudinal motion of the table carrying the work; the gearing which communicates that motion ought to be extremely smooth and accurate in its action; such as the rack and helical pinion; and the pitch-point of the rack and pinion ought to be as directly as possible below the cutting tool.

During the return stroke, the tool is lifted clear of the work, and the motion of the rack and pinion is reversed by means of self-acting reversing gear; and the train of wheelwork which produces the return stroke is so proportioned as to give an increased speed of motion to the table, usually about double that of the cutting stroke.

The transverse traversing motion of the tool-holder is intermittent, being made during the return stroke of the table. The combination which directly produces it is usually a transverse horizontal screw driving a nut that is fixed to the tool-holder. The screw is driven by a suitable train of wheelwork, the first wheel of which is driven by a click, usually of the reversible kind. The extent of traverse after each cutting stroke can be regulated by the help of adjustments of length of stroke, or of change-wheels.

For cutting straight surfaces of more or less complex cross-section, and especially for cutting straight grooves and straight rectangular holes, such as key-ways and slots, the slotting machine is used. In this machine the tool-holder or cutter-bar usually slides vertically in a guiding groove in the slide-head, which is carried by a strong overhanging frame. Below the slide-head is a table to which the work is secured, capable of being turned about a vertical axis, and traversed horizontally in two rectangular directions, so as to bring the work into any required position relatively to the cutting tool.

Fig. 5231 is an end elevation of a planing machine by William Muir and Co. of Manchester. The top has angular surfaces, forming a slide for the reception of the table, which is also cast in one piece, is very strong, and is perforated on the top with flanged slots for facilitating the fastening of the work to be planed. Underneath the bed is fitted a strong rack, gearing into a flanged pinion, on the shaft with which is keyed a spur-wheel, on the same shaft upon which is placed the driving pulley. This gives the quick return motion to the table.

There are uprights, bolted to the projections cast on the bed for their reception, the vertical faces of which are planed and squared for setting the work. Each is fitted with elevating screws and bevel-gearing, and coupled by the cross shaft, thus ensuring that the cross slide shall be always square with the top of the table. The cross slide is fitted with the feed-screws and feed-shaft, geared together at the ends. In this machine there are two saddles on the cross slide, each carrying a swivelling slide. Each of those slides carries a vertical slide, which can either be adjusted independently, or coupled together, for a self-acting downward or bevel cut; on the face of each vertical slide is bolted an angling plate, for clearing the tool of the work, and on this latter is hinged the tool-carrier, fitted with wrought-iron tool-holders and pinching screws.

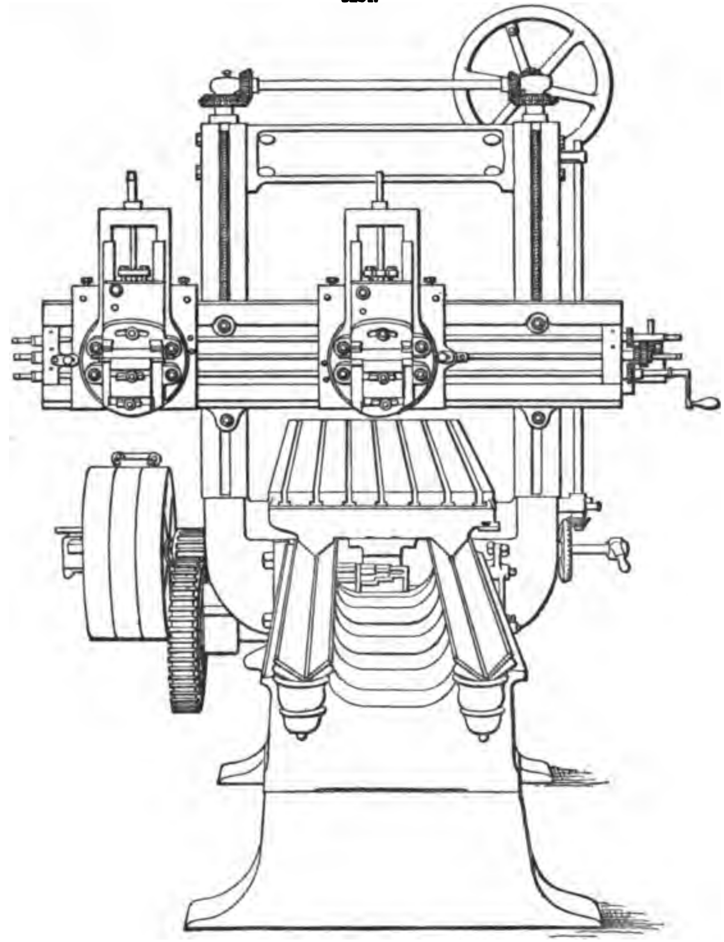
Figs. 5232, 5233, and 5236 are of a planing machine, designed by Wm. Sellers, of Philadelphia, and made in England by Sharp, Stewart, and Co. Sellers has, in this machine, greatly simplified the construction of metal planing machines; he has provided a more thorough system of bracing for the bed between the uprights; imparted a smooth and uniform motion to the table upon which is placed the metal to be planed; placed the pulley-shaft so that its axis may be parallel with the line of motion of the table, thus enabling these machines to be placed parallel to lathes, and permitting a better arrangement of workshops; imparted a feed-motion to the cutting tool, by positive gearing and not by friction, thereby rendering its movement more certain; operated the feed-gearing from the driving gear of the machine and giving the cutting tool its feed either before it commences its cut or after it has finished the same, which cannot be done when the feed is operated from the table; and operated the belt-shifter in such a manner that the belt shall only be moved its own width, diminishing the wear upon it, and decreasing the width and weight of the driving pulleys.

Sellers furnishes the table of the machine with a rack of an ordinary construction, and operates this rack by a worm or screw, which enables the driving shaft to cross the bed diagonally, passing out in a position near enough to the upright, which carries the slide-rest and cutting tool, to enable the driving belts to be within reach of the operator.

The machine has a peculiar mode of transmitting and arresting motion by means of a ratchet which must be the driver, and a double pawl attached to the object to be driven, so that, while retained in gear with the ratchet, motion will be imparted to the object to be driven, until,

by the interposition of a suitable stop, the continuous motion of the ratchet will lift the pawl out of gear.

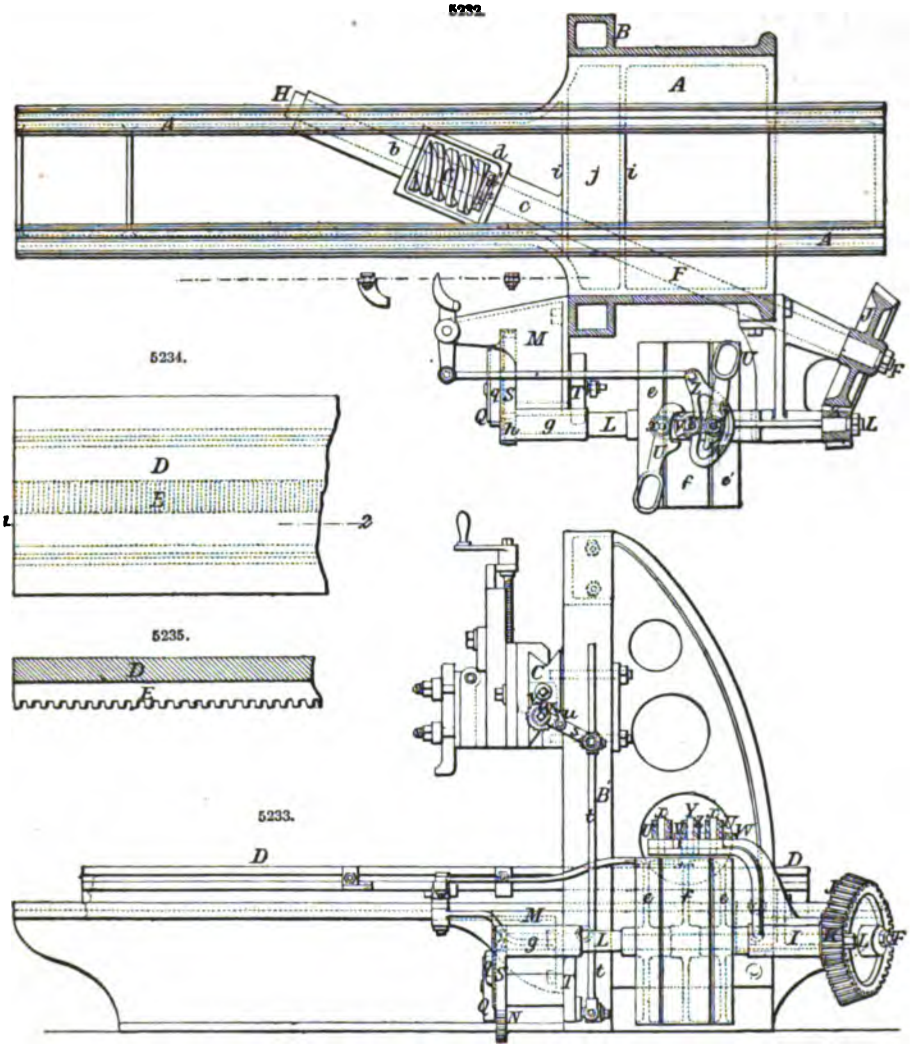
5231.



This pawl is provided with a suitable projection, having upon it a friction-pad which is always in contact with the driver, so that, when the motion of the driver is reversed, the friction-pad reverses the position of the pawl, and causes it to present its other end to the ratchet, which is thus enabled to move it in the opposite direction, until the pawl is again lifted out of gear by the interposition of a suitable stop as before.

A, Figs. 5232, 5236, is the bed of the machine, to opposite projections of which are bolted the uprights B and B′, carrying the slide C. The top of the bed A is provided with V-shaped grooves extending its entire length, in which slides the table D, it being provided with downward projecting ribs *a a*, of corresponding bevel to the V grooves. To the under side of the table and central between the slides *a a*, and extending its entire length, is attached the rack E. Motion is communicated to the table by means of a worm upon a shaft F, crossing the bed diagonally, in the manner best seen at Fig. 5232, which worm G gears with the rack E. The driving shaft F revolves in bearings *b* and *c*, cast in the bed and connected by a trough *d*, serving as a receptacle for the lubricating material in which the worm G is kept constantly running. The end of shaft F in the bearing *b* receives a portion of the thrust from the motion of the table, under the cut against a step H, whilst a portion of the lesser thrust, during the return motion of the table, is received against the hardened collars d^1 and d^2, at the other end of G, d^1 being fastened against the end of bearing *c* and d^2, attached to the shaft F; the remainder and smaller portion of this thrust is received against the sides of the bearings *b* and *c*. The shaft F is at the end opposite to the step H, supported in a third bearing attached to a stand I, and outside of this bearing it is fitted with a bevel-wheel J, which is driven from a pinion K on the pulley-shaft L, the latter having the usual fast pulley *f*, and loose pulleys *e* and *e′*, transmitting alternately by means of an open and crossed belt from the counter-shaft above the power for the reciprocating movement of the table. In Figs. 5234, 5235, it will be seen that the position of the teeth in the rack of the table slightly varies from a right angle to the line of motion; this is done to counterbalance the side pressure which would otherwise be produced upon the table by the action of the screw under the cut.

The advantages of the improvements as regards facilities for bracing the bed in the parts under strain from the cut will be obvious on reference to Fig. 5232. Here it will be seen that the sides



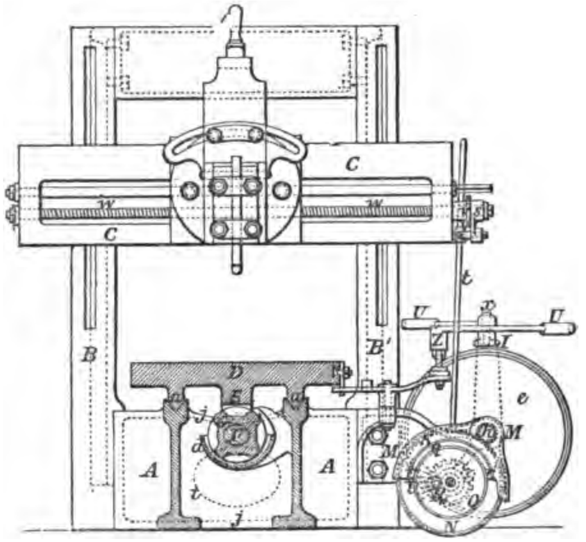
5232. 5234. 5235. 5233.

of the bed directly between the posts and the uprights B and B′ are firmly braced by a box-shaped connection consisting of the vertical ribs *i i*, and top and bottom plates *j* and *j*. To give the utmost capacity to the machine, it is very desirable to bring the driving belts within reach of the operator for convenience, and to accomplish this in the ordinary rack planer, the space between the uprights is usually occupied by the gearing, and admits of a very narrow brace, and in the screw planer this brace must be much diminished in height to give room for the screw, so that the strengthening of the most vital part of the machine is rendered very difficult. In addition to the above braces the bearings *b* and *c* of the shaft F, united by means of the trough *d*, connect the two sides of the bed in such a manner as effectually to strengthen it, and enable it to resist the end thrust of the shaft F.

The mode of transmitting and arresting motion by means of a ratchet and pawl is applied as a feed-motion for the cutting tool, the parts constituting this feed-gearing being carried upon a stand M, which is bolted to the front of the upright B′. The pulley-shaft L has one of its bearings *g* in this stand, outside of which bearing it is provided with a pinion *h*. This pinion gears into a spur-wheel N, which has a long sleeve journal N¹, Figs. 5237 to 5239, in the stand M, and is, upon its outer face, provided with an internal ratchet-wheel O. To the end of a shaft P, passing through the sleeve N¹, is attached, in front of the ratchet-wheel O, a circular plate Q; this plate carries the double pawl R, which has its point of support on a pin *k*, Fig. 5239, projecting from a block *l*, the latter being fitted to a corresponding recess in the plate Q, to which it is further secured by the rivets *m m*. The friction-pad *n* is attached to a flat arm *o* of the pawl R, and consists of a

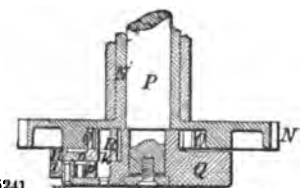
piece of leather riveted or otherwise secured to the arm *o* on the side next to the face of the ratchet-wheel O, with which it is held in contact by the pressure of a spiral spring *p* confined in a recess in the block *l*. At the end next to the spur-wheel N the stand M is formed into a semicircular shield or cover S, Fig. 5240, protecting the wheel N and pinion H, and acting as a safeguard to the workman. A flange *q* projects on the front side of this cover, and embracing the circular piece Q serves at *r* and r^1 as a double stop for arresting the motion of the plate Q and its shaft P in either direction.

5236.

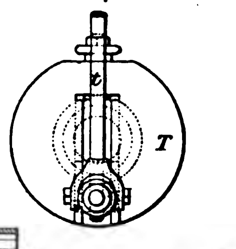


The motion given to the spur-wheel N by the pinion *h* alternately in opposite directions is transmitted to and arrested in the shaft P, the operation of the device to this end being as follows;— On reference to Fig. 5240 it will be seen that the pawl R is represented as resting with its arm O against the stop *r*, and in such a position in regard to the internal ratchet-wheel as to be out of gear with the teeth of the latter. Assuming now the ratchet-wheel to be rotated in the direction of the arrow, it will be evident that the friction produced by this motion upon the pad *n* of the pawl R, Fig. 5241, will change the position of the latter by drawing it around on its fulcrum in the direction indicated by a second arrow, Fig. 5240, thus throwing the pawl into gear with the first approaching tooth of the ratchet-wheel, and thereby transmitting the motion of the latter to the shaft P and plate Q, to which the pawl is attached.

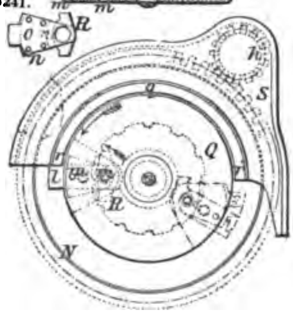
5239.



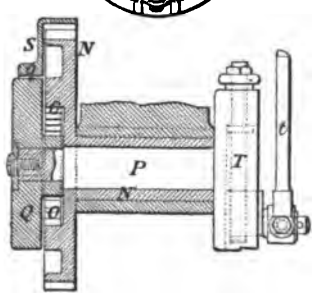
5237.



5241.



5240.



5238.

In this manner the shaft P continues to be driven, until the pawl R approaching the stop r^1 is again shifted to its former position, and thrown out of gear by coming in contact with the said stop r^1, and immediately after the motion of shaft P is positively arrested by the block *l* coming in contact with the stop r^1, the ratchet-wheel *o* being free to continue its rotary motion. As soon, however, as the motion of the spur-wheel N is reversed, the friction of *o* upon the pad *n* throws the pawl R into gear, and the shaft P is moved in the opposite direction until arrested by the stop *r*, in the manner before described. The alternate movements of the shaft P in opposite directions are by means of a crank-wheel T which it carries, transmitted to a vertical rod *t*, which through a vibrating arm *s*, pawl *u*, and ratchet-wheel *v*, gives the requisite movements to a screw *w* in the slide C for feeding the cutting tool.

The device for controlling the position of the two belts which impart motion to the machine in opposite directions is shown in Fig. 5232, in which U U are the belt-shifters, supported by and movable around their respective centre studs *x x*. V is a tooth of an external, and W of an internal wheel, both being upon one piece Z, supported by and movable around the stud Y, the tooth V gearing with a corresponding space upon one belt-shifter, and the tooth W with the other. The segments upon Z are central between the extremities of their movement, and both shifters bearing upon their respective loose pulleys. Supposing now Z with its segments to be passing this position while moving in the direction of the arrow, Fig. 5232, it will be seen that the tooth W having just completed the movement of its shifters in passing out of gear with the same at the

instant that the tooth V goes into gear with its shifter, moving it until this tooth goes out of gear, when no further motion of the shifters can take place until the motion of the segments is reversed. If now the segments be moved in the opposite direction, the tooth V having passed out of gear with its shifter last, will be in a position, the motion being reversed, to go into gear first, and consequently the shifter which completed its movement last, will now complete its movement first, and the tooth V will pass out of gear with it as the tooth W goes into gear with its shifter. The advantages of this arrangement are, that the position of engaging teeth on the segment-wheel and shifters determines the difference in time between the movements of the two shifters; these may be varied, so as to allow the belt moving off the driving pulley to be entirely clear before the other goes on. It is evident also that when the segment-teeth V and W have passed out of gear, the belt-shifters U U are locked, so that no movement can take place until the segment-wheel is moved, thus making the position of the shifters perfectly secure.

The use of an internal and external wheel causes the driving and driven surfaces, when in action, to move away from each other, making the movement easy and without strain, which would not be the case if both segments were of the same character.

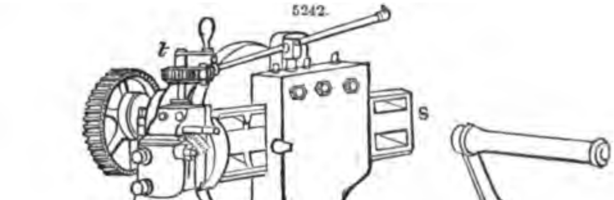
Shaping Machines.—Shaping machines that have a cutt ng movement of the tool, have come into general use for short work. The greater convenience of adjusting—the positive stroke, and the better facilities for chucking, or fastening the work, present strong arguments in their favour.

On planing machines the work must in all cases be fastened on the horizontal face of the platen, or to angle-plates bolted to its face, but shaping machines have generally both vertical and horizontal faces, to which the work can be fastened; besides being usually fitted with chucks and other appliances which cannot be so well used on planing machines. The positive stroke given by the crank is often convenient, and sometimes a necessity, in planing slots and grooves, when the tool must stop at a certain point.

The ingenious compound crank movement invented by Whitworth, generally known as the quick return movement, economizes time and gives to the shaping machine the advantages of the planing machine in this respect.

This motion not only saves time on the back stroke, but equalizes the movement in the forward or cutting stroke, an advantage of even more importance than the time saved. An effect about the same is attained by the slotted link, which is used by many English tool builders. Elliptical gearing is also used to effect the same purpose.

5242.



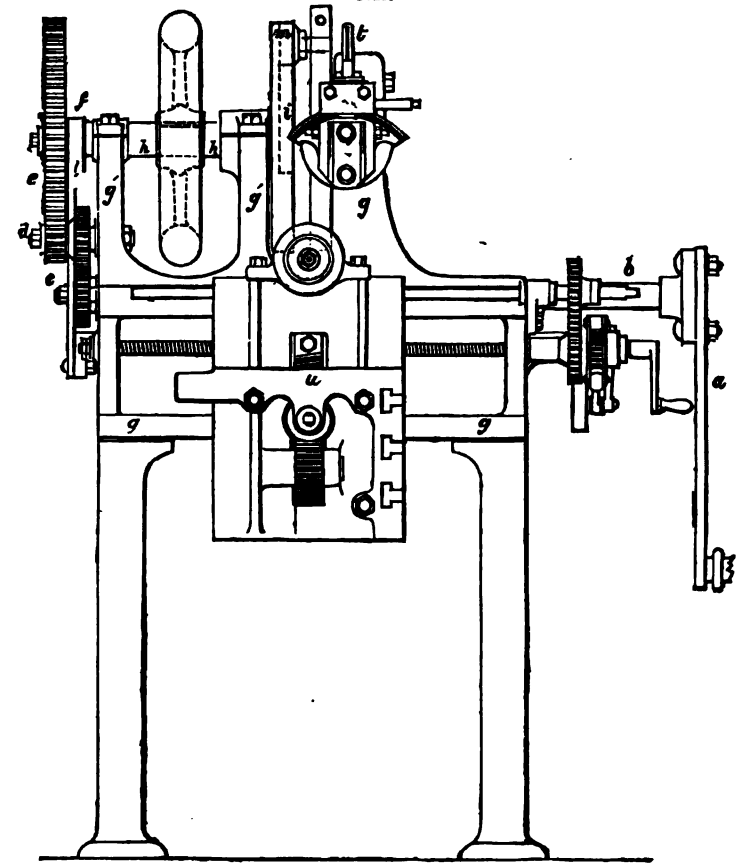
Figs. 5242, 5243, are views of 12-in. stroke shaping machines by Wm. Muir and Co., Manchester. *a* is the handle; *b*, the driving shaft; *c*, the driving pinion gearing into the change-wheels *e e*; *f f*, bearings upon the frame *g g'* carrying the shaft *h h*. Upon this shaft is cast a disc having a V slot *i*, within which is fixed a carrier stud adjustable with a V-shaped base not shown in the section. The stud works in a square slot, at right angles to the slide-bar, and it gives motion to the slide-bar; S is a slide-bar carrying the tool-head; *t*, adjusting screw of the tool-holder; *u*, the work table; *m*, Fig. 5242, a movable vice which can be attached to the table either on the top for light work, or at the side for long pieces of metal.

In Wm. B. Bement and Son's 14-in. travelling-head shaping machine, Figs. 5244, 5245, *a* is the main frame of the machine, along the tops of which the travelling head *b* moves; and the side is arranged for receiving the tables *c* and *d*, which have a lateral and vertical adjustment. The table *c* has a horizontal and vertical planed surface with T slots for clamping work. The table *d* is arranged with a vice for fixing work of plain form. The cutting bar *e* has a movement varying from zero to 14 in., and an adjustment of 10 in. The quick return movement is produced by Whitworth's eccentric arrangement at *f*.

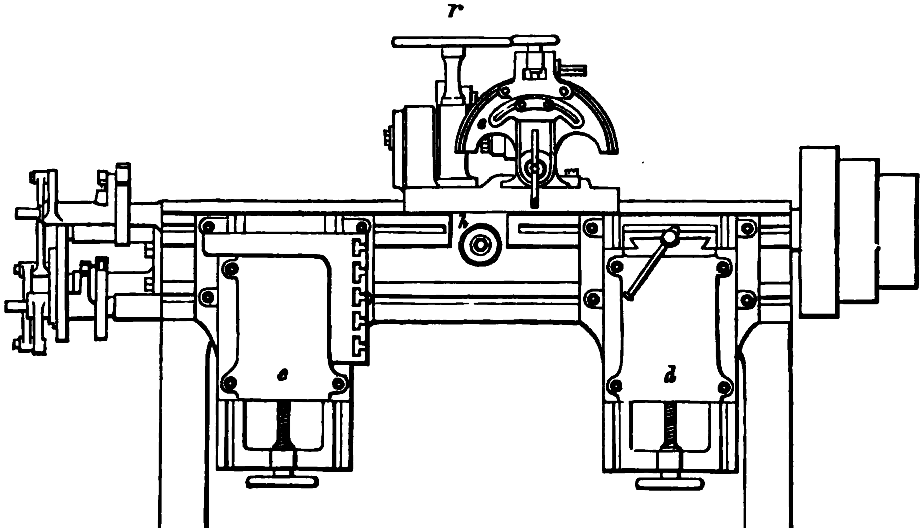
The driving shaft runs the length of the machine and carries a splined pinion which gears the large wheel *g*, the pinion moving with the travelling head.

The crank for giving the feed is driven by a small pinion on the end of the driving shaft.
The feeding arrangement is shown on the end view, and consists of a screw connected by a long lock-nut to the travelling head, which is thrown in and out by a handle not seen in the drawing.

5243.



5244.



n is connected to the stud *h* by a worm and tangent-wheel, to give rotary feed, for shaping work which cannot be turned in the ordinary manner in a lathe.

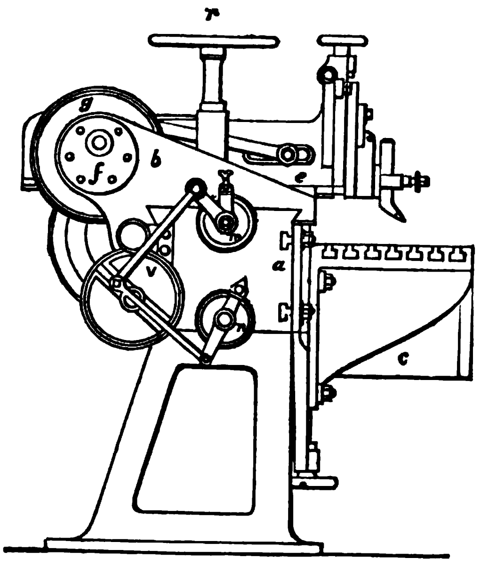
The hand-wheel *r* gives a quick lateral adjustment to the travelling head by a rack and pinion.

The arrangement for holding and feeding the tool is of the ordinary form.

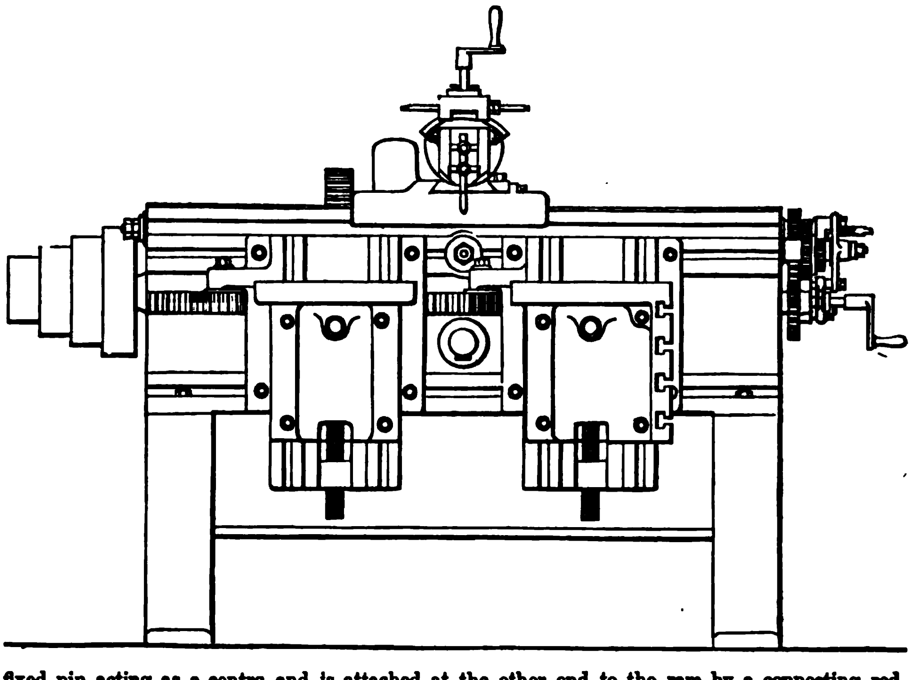
Fig. 5246 is of a similar shaping machine, by Wm. Muir and Co.

Fig. 5247 shows Sharp, Stewart, and Co.'s shaping machine.

This machine, in common with the generality of shaping machines having a stroke of more than 6 in., is composed of a bed to which are fixed one or more adjustable tables for carrying the work to be operated upon; on this bed slides a saddle which carries the tool-holder. Where the machine differs from the ordinary one is in the mode of giving the reciprocating motion to the ram carrying the cutting tool.



The main shaft, which is driven from overhead gearing, passes at the back of the machine, and has keyed to but sliding on it a pinion which drives a large wheel made with step-teeth. To reduce the irregularities, on the disc of this wheel is a slot in which can be adjusted a crank-pin, so as to vary at will the length of the stroke. On the crank-pin is a block fitting and sliding in a link, which link oscillates at the lower extremity on a



fixed pin acting as a centre, and is attached at the other end to the ram by a connecting rod, thus obtaining a reciprocating motion to the ram with a greatly accelerated return. The ram is made hollow, of U-shaped form, so as to allow the connecting rod to pass in the middle, and thus avoid tendency to side thrust.

Curvilinear Slotting Machine, by Sharp, Stewart, and Co., Fig. 5248.—The base of the machine consists of a bed-plate, similar to that of a lathe, at one end of which is fixed the head carrying the driving gear, while the remainder forms a slide upon which a table supporting the wheel to be slotted can be traversed. This table is double, the lower part being rectangular, and fitted to the bed of the machine, and the upper part circular, furnished with worm-teeth round its circumference, and capable of revolving on the lower portion. The wheel to be slotted is bolted down to this upper

table by bolts passing through the boss, and a slow revolving motion is given to it by a worm gearing into the teeth around the circumference of the table. The cast-iron block interposed between the wheel and the table enables the height of the wheel to be adjusted, so that the centre of the

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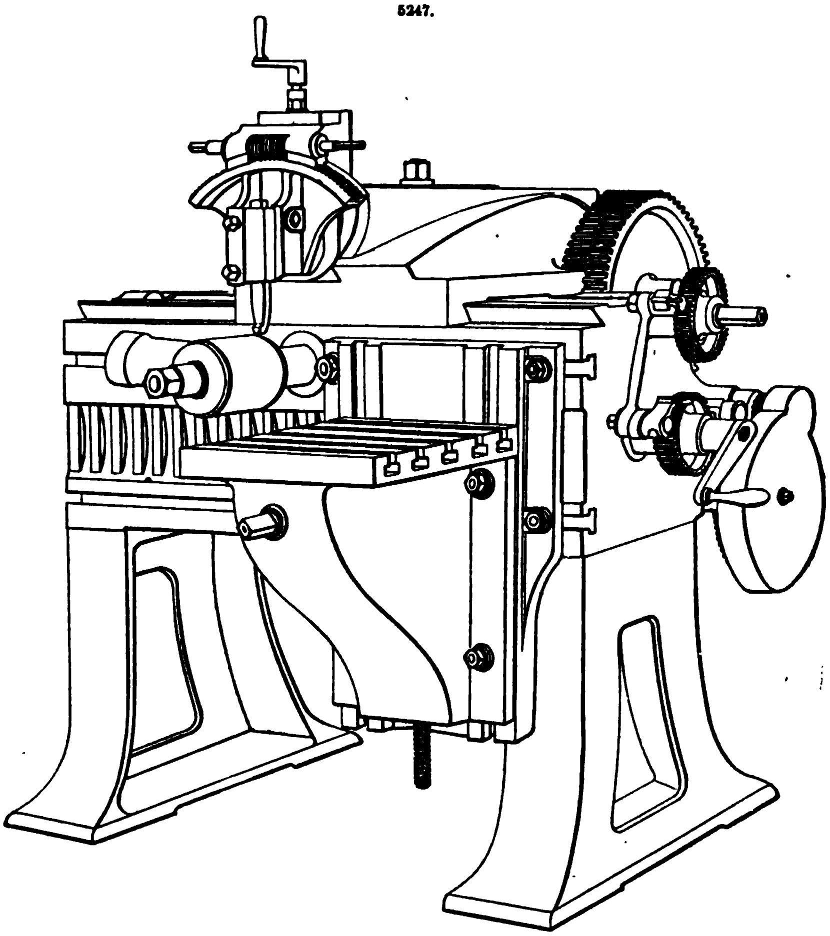

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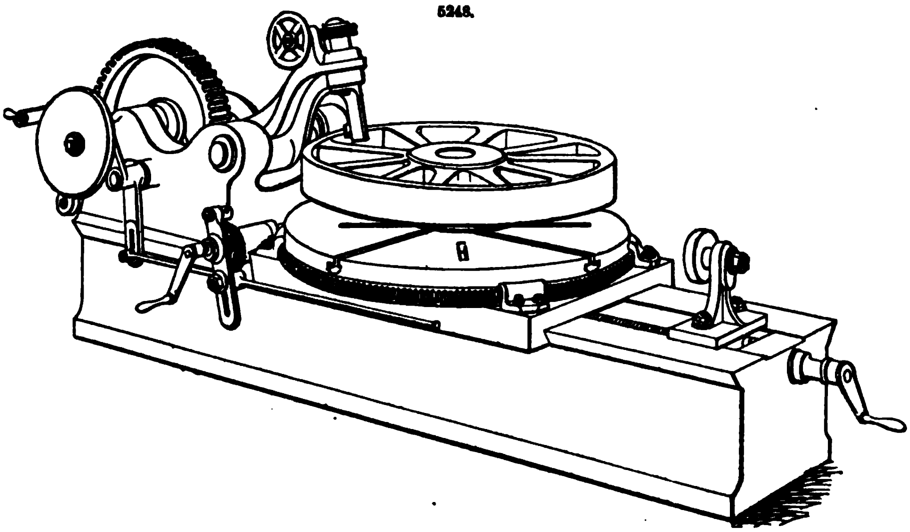


wheel is in a line with the centre of the shaft upon which the lever working the cutting tool vibrates; different blocks being used to suit the various thicknesses of wheel bosses. The blocks have circular ledges formed on them, which enter the holes in the wheel bosses, and thus allow the wheel to be at once set, so that their centres coincide with that of the revolving table. The fixed head of the bed-plate carries a short shaft, to one end of which is keyed a wheel furnished with a crank-pin adjustable in a slot on the face of the wheel, so that the stroke given to the cutting tool can be varied. This crank-pin carries a brass block working in a slot in a bent lever which vibrates on a short shaft also supported by the fixed head, and carries at its other end the tool-holder. The crank-wheel shaft revolves from left to right, the tool has therefore a slow downward and quick return motion given to it. At the outer end of the crank-wheel shaft is fixed a spur-wheel, furnished with a cam groove for working the feed-motion of the revolving table, and driven by a pinion on the counter-shaft carrying the fast and loose pulleys.

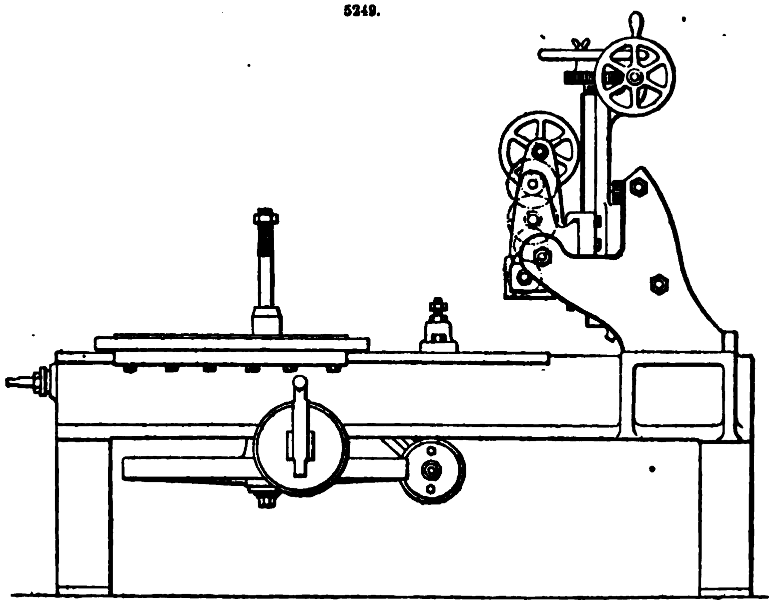
The upper part of the tool-holder forms a short shaft passing vertically through the end of the vibrating lever, and furnished at its upper end with a worm-wheel. By means of a worm gearing into this wheel and worked by hand, the tool can be made to revolve—the point describing an arc of a small radius—and it is thus enabled to cut out the curve that occurs at the junction of the rim and spokes of an engine-wheel. The circular motion of the table is of course stopped while this operation is being performed. Besides being bolted down to the revolving table, the wheel which is being slotted is supported under its rim by two pulleys, carried by a slide, adjustable on the bed of the machine, to suit wheels of various sizes. The machine is compact and well arranged, and turns out excellent work.

Wheel-cutting Machine.—A wheel-cutting machine, for shaping the teeth of wheels, may be regarded as a special form of the shaping machine, in some cases combined with the turning lathe. The wheel to be cut is fixed on mandrels carried at the end of a rotating spindle, mounted on a head-stock. Sometimes that spindle acts as a lathe-spindle, while the wheel is being turned. When the pitching and tooth-cutting are to be begun, a large worm-wheel, permanently fixed on the spindle, is made to gear with a tangent-screw, by means of which it is successively turned through a series of angles, each equal to the pitch-angle; first, for the purpose of pitching the wheel, or marking the pitch-points of the teeth on the pitch-circle, and then for the purpose of changing the position of the wheel after each tooth has been cut, preparatory to cutting the next tooth. The figures of the teeth are given approximately by casting, and finished by cutting.

Each stroke of the cutter is guided so as to take place along a straight line. In spur-wheels that straight line is parallel to the axis; in bevel-wheels it traverses the apex of the pitch-cone; in skew bevel-wheels it is a generating line of the hyperboloidal surfaces of the teeth. When a single cutter is used, the slide in which it works is guided into the proper positions for the successive strokes by a templet shaped like a tooth or like the space between two teeth. In cutting the teeth of spur-wheels, a rotating circular cutter is used; and the form of the cutting edges of its teeth is the counterpart of that of the space between two teeth.

Fig. 5249 illustrates Wm. Muir and Co.'s wheel-cutting and dividing machine, to cut spur, bevel,

5249.



worm, and skew wheels, either in metal or wood. It is mounted on two feet, and has a slide table movable along the bed by a screw so that the wheel or other object to be operated upon may be quickly and accurately brought in contact with the cutter—which has a vertical and angular movement, communicated to it by a worm and wheel. There is a fixed head-stock and gearing for driving the cutters, and a vertical slide with full swivel indexed so as to give the correct curve and

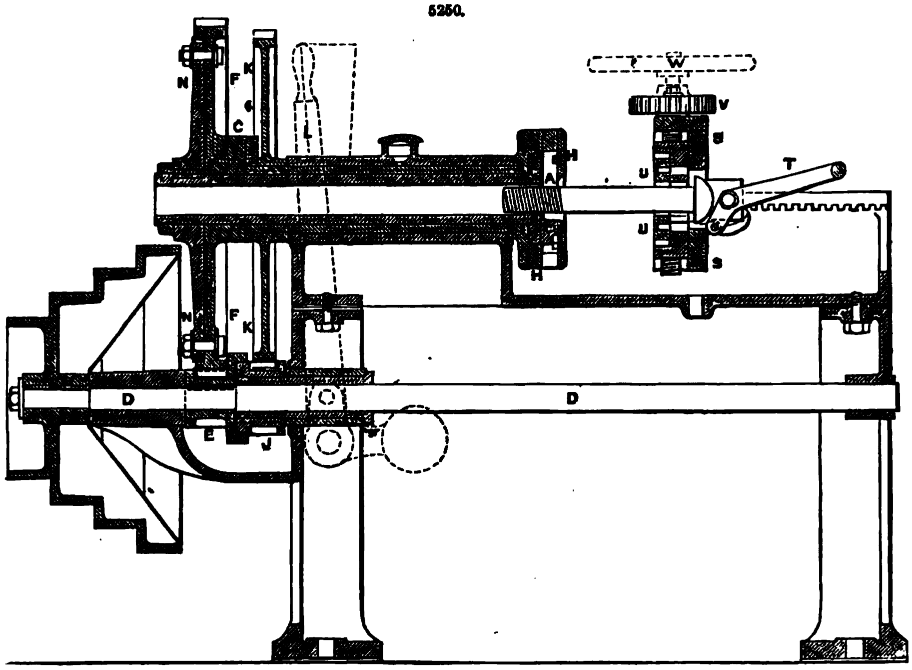
angle to cutter. The machine is furnished with a machine-cut dividing wheel for all numbers of teeth up to 100, and for composite numbers above; it has also a division wheel and handle, and an adjustable swing driving apparatus with grooved cones for driving by gut band.

Screwing Machine.—In the screwing machine designed by Wm. Sellers, of Philadelphia, the screw-thread is cut in a single operation, and the finished bolt is released by the withdrawal of the dies, the machine being driven continuously in one direction, without reversing or stopping.

Sellers' machine, as made by Sharp, Stewart, and Co., is shown in Figs. 5250 to 5255. Fig. 5250 is a longitudinal section through all the working parts of the machine, and Fig. 5251 an end elevation; Fig. 5254 a longitudinal section of the die-box, enlarged, and Fig. 5255 a front elevation of it, with the cover-plate removed, in order to show the dies.

The dies for cutting the screw-threads are in three separate pieces A A A, Fig. 5255; these are advanced and held in the required position for screwing the bolt by means of eccentric ribs or cams fixed upon the cover-plate at B B B, which work in a notch in the edge of each die. In working, the die-box C revolves in the direction of the arrow, being driven from the driving shaft D, Fig. 5250, by the pinion E and spur-wheel F, and the projecting clutch G, on the back of the wheel F, carries round with it the cam-plate H, which thus revolves at the same speed as the die-box C, so that the relative position of the cams and dies remain unaltered in revolving, and the dies are held up to the proper position for cutting the thread without alteration during working.

5250.

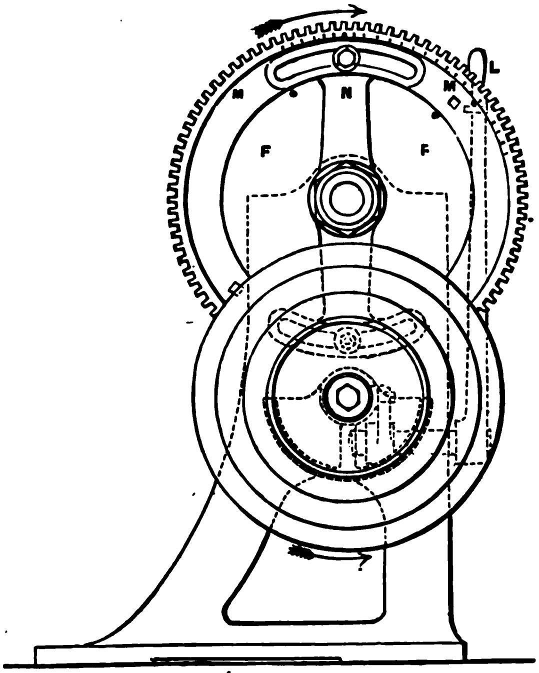


When the screwing is completed, the bolt is released by the dies being all simultaneously withdrawn by means of the cams; this is effected by the second pinion J, Fig 5250, gearing into the spur-wheel K fixed on the shaft of the cam-plate H. This pinion J is a little larger in diameter than the driving pinion E, and runs loose on the driving shaft D during the time that the dies are in operation cutting a screw; but when that is completed, the conical friction-clutch between the two pinions is caused to engage by pressing forward the handle L, shown dotted in Fig 5250, whereby the spur-wheel K, being of a little smaller diameter than the wheel F, is made to revolve faster than the latter, and causes the cam-plate H to over-run the die-box C; the dies A, Fig. 5255, are thus made relatively to move back along the cams, so that they are withdrawn from the finished bolt, which, being released, is drawn out by hand, while the machine is still driven continuously in the same direction, without stopping or reversing. The handle L on being released is immediately brought back to its original position by means of the counterbalance weight attached to it, thus disengaging the pinions E and J, and pressing the loose pinion J against a leather collar on the end frame of the machine, the friction of which checks the motion of the pinion J and the spur-wheel K of the cam-plate, allowing the die-box C to overtake the cam-plate again; the dies are thus moved forward along the cams till they are again in their original working position, ready for cutting a fresh thread.

The adjustment of the dies to the exact position required for the size of the bolt to be cut is accomplished by means of a graduated index M, Fig. 5251, on the spur-wheel F, which drives the die-box C. The wheel F is loose on the shaft of the die-box, and in working is clamped by set screws to the arm N, Figs. 5250, 5251, which is keyed on the shaft. For advancing the dies, the arm N is turned forward in the direction of the rotation, as shown by the arrow, carrying the dies forward along the cams, the latter being held stationary at the time by holding the spur-wheel K

that is fixed on the cam-plate shaft. The dies are thus advanced to the position for cutting, and the spur-wheel F is then clamped securely to the arm N by the set screws, having previously been turned so that the projecting clutch G on the back of the wheel F is engaged with the wheel K of the cam-plate. The machine is then ready for starting to work. The total length of the graduated index corresponds with the total length of the cams; and two holes in the wheel F for each of the set screws are sufficient to admit of adjustment throughout the entire range of the index, by means of the slotted arc at each extremity of the arm N.

5251.



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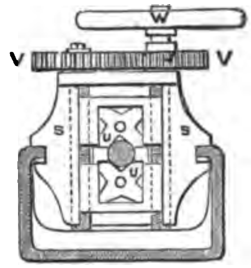

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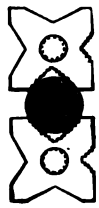

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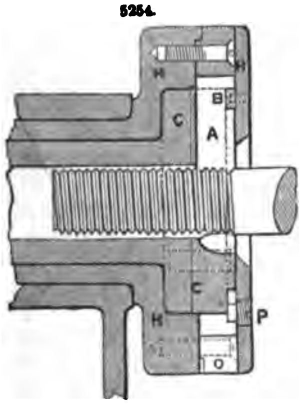

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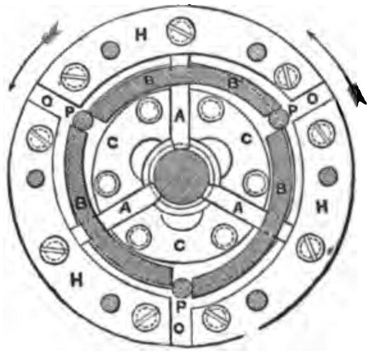
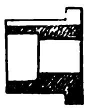


For changing the dies in the die-box, the spur-wheel K is turned forward by hand, as far as it will move; this brings the dies opposite the openings O in the cam-plate H, Figs. 5254, 5255. The three fixing screws P are then slacked back till their inner ends are flush with the inside of the cover-plate, when the dies can be pushed out through the holes O. In putting in the fresh dies, each die is inserted in turn, and pushed down until the notch in its edge comes opposite the fixing screw P, which is known by a shoulder on the screw-driver; and the cam-plate is worked backward and forward by hand, by means of the wheel K, to make sure of the die being properly placed with the notch fitting on the cam; the fixing screw is then set up, which secures the die from falling out. In order to cut a full screw-thread on the bolt in once running up, the dies are cut with a perfectly full thread throughout, and of such size as to fit the bolt when it has the thread cut complete upon it. The tops of the die-threads are then eased off on the side where the bolt enters, as in Fig. 5254, commencing at the base of the thread, and terminating at the top of the third or fourth thread from the point of entering. The thread on the bolt is thus formed by

a succession of cuts, each one deeper than the preceding, until the full depth is attained. When the machine is used for tapping nuts, the cutting dies are removed, and the tap-holder, Figs. 5256, 5257, is inserted in the hollow spindle of the die-box, and secured from turning by a blank die, Figs. 5258, 5259, which serves as a key fitting into the notch in the tap-holder. The bolt or nut to be screwed is fixed in the sliding holder S, Figs. 5250, 5252, sliding freely on the top edge of the framing; the handle T is made with a finger on it, to fit in a rack on the framing, which gives sufficient leverage for the momentary pressure that has to be put upon the bolt on its first contact with the cutting dies to ensure its entrance. The clamps U for gripping the bolt or nut, shown separate in Fig. 5253, are opened or closed simultaneously, one up and the other down, by two right-and-left-handed screws geared together by the pinion V, and worked by the hand-wheel W. It is essential that the bolt or nut to be screwed should be truly in the axis of the die-box, which is ensured by boring the clamps in their places in the machine, and they are afterwards slotted to the required shape. In cutting new dies, or recutting old ones, a set of master-taps is used; the leading end of the master-tap is supported in a circular timber, which slides inside the hollow spindle of the die-box.

5256.



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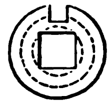

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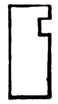


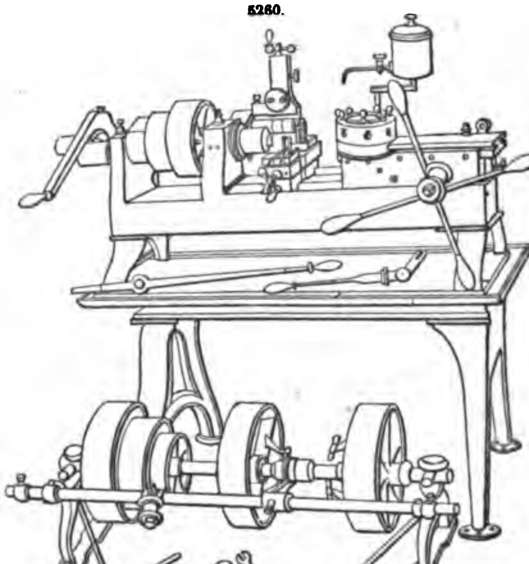
5259.

The dies are then pressed close upon the master-tap by means of the arm N on the spindle of the die-box, Fig. 5250, and the machine is run forward and backward, the dies are again closed upon the tap, and the process repeated until a full thread is obtained. A small stop is first inserted in the clutch G between the spur-wheels F and K, so as to make them immovable with respect to each other during the process of cutting the dies.

In this machine the necessity of setting up the dies by hand between successive cuts is obviated, as they are set up at the first by the graduated index of the cam-plate to the exact diameter required for the finished bolt, and the screwing is completed in once running the bolt up. With each machine a table is prepared, showing the position on the index to which the pointer has to be set for cutting bolts of the various diameters within its range; and a slight change in the position of the pointer will make the bolts slightly larger or smaller, as the case may require. When the dies have become worn, and have been recut, a readjustment of the index readily gives the means of bringing them up to exactly the same diameter as previously, so that the size of bolt is not altered by recutting the dies. The original adjustment of the index is made by actual trial of the different diameters of bolts in the machine, the results being tabulated; and this is done again when the dies are recut.

This screwing machine has the advantage of rapidity of action, producing a perfect screw-thread in once running up, while the time usually required for running back is saved by the plan of withdrawing the dies and releasing the bolt. The machine is never required to be stopped, except for changing or repairing the cutting dies, and does not need the application of a crossed belt or reversing apparatus for driving it, since it runs continuously in one direction only. It is of small size in proportion to the work it accomplishes, and is on a plan very convenient for the workman using it. As the dies can be readily adjusted to any diameter of bolt for which the machine is adapted, they can be worn down for a long time before requiring renewal.

5260.



A screwing machine made by the Brown and Sharpe Manufacturing Co., Rhode Island, is shown in Fig. 5260.

This machine is suitable for making, from bar iron, all kinds of screws and studs ordinarily used in a machine shop. Nuts can be drilled, tapped and one side faced up, and many parts of sewing machines, cotton machinery, gas and steam fittings made on this machine, with a great saving of time and labour. Size of hole through spindle is 1¼ in. Size of holes in revolving head, 1$\frac{1}{16}$ in. Length that can be milled, 6 in. The friction-pulleys on the counter-shaft are 14 in. diameter, and 3½ in. wide. Counter-shaft should run 170 turns a minute.

Milling Machines. — Milling, or slabbing machines, as they are sometimes called, are the most effective and the most speedy of all machines directed to metal cutting.

Operating with rotary serrated cutters, we find by applying the rule of multiplying the length of the edge by the rate of movement, that milling machines should displace a great deal more metal in a given time than either turning or planing machines.

From the substantial manner in which the cutting tools are held and guided in milling machines, their edges can be much longer than in other cases.

The reason that we cannot avail ourselves of milling machines for all kinds of work is that the surfaces have to be cylindrical, with a large number of edges that must be exact duplicates, and stand in a positive position; the least derangement or wear upon one or more of the edges carries them below the cutting plane, and throws their work upon the next, which is then almost sure to break. The processes of forging, finishing, hardening, and sharpening milling tools are expensive and difficult, and another objection is that the cutting edges having necessarily a profile corresponding to the work, cannot, except for flat surfaces, be used as tools for general purposes.

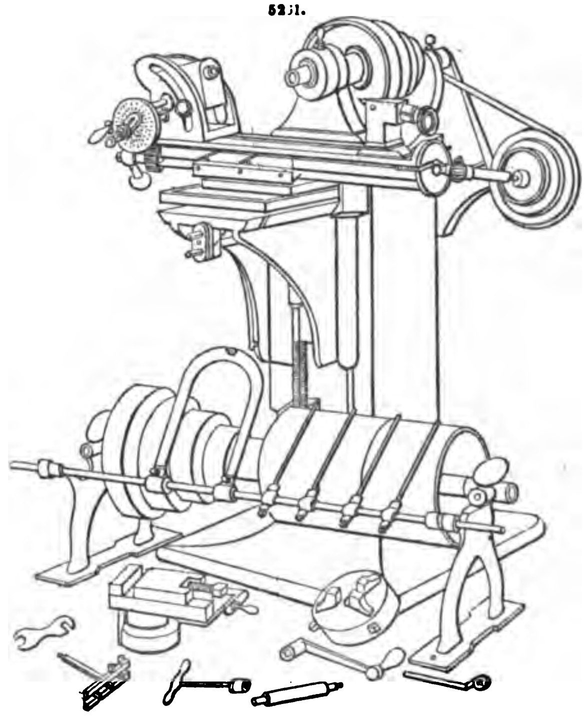
Milling, as a process, is speedy and profitable on work where there is no danger of injury to the cutters, and where the work is a duplication of pieces, that have the same form. In practice we find this carried out. For cutting clean iron or steel, where is no danger of meeting with scale or hard spots, and when a large number of cuts of the same kind are to be made, we invariably find the work done with milling tools.

Cutting the teeth of wheels is an example; the blank is first turned out of good, clean material, and the operation of cutting is that of making duplicate notches or spaces between the teeth. In the manufacture of small arms or of sewing machines, where the forgings are made from the cleanest iron or steel, and carefully picked to remove the scale, they are successfully and rapidly shaped by milling tools.

Machines for milling consist of a cutter-spindle, having a lateral adjustment, and a movable platen to carry the work. Their modifications are almost endless, being in a sense special tools, and we scarcely meet with two that are arranged in the same manner unless applied on the same work.

Fig. 5261 is a universal milling machine made by the Brown and Sharpe Manufacturing Co., Rhode Island. It has an elevating knee upon which are arranged a sliding plate, a swivel-plate, and a sliding carriage with a revolving cutter-head. Thus, this machine, which is of particular service in sewing-machine making, has all the movements of a plain milling machine, and the following in addition;—The carriage moves and is fed automatically, not only at right angles to the spindle, but at any angle, and can be stopped at any required point. On the carriage, centres are arranged in which reamers, drills, and mills can be cut, either straight or spiral. Spur and bevelled gears can also be cut. The head which holds one centre can be raised to any angle, and conical blanks placed on an arbor in it, cut straight or spirally. Either right or left hand spirals can be cut.

5261.



Crucible steel being more homogeneous than iron, is best adapted to milling processes, the hard pins are not met with as in iron, and when the cutter-heads can have a sufficient diameter to allow the cutters to be mounted in such a way as to be removed to sharpen them, there is no doubt but a great gain can be made, in any kind of cutting to which the process can be applied.

David Hanson's Flanging Machine, Fig. 5262, made by Wm. Muir and Co., Manchester, is an extremely useful tool for boiler makers. The tube to be flanged is fixed on a powerful chuck, furnished on its lower side with a bevel gear driven directly from the pulley *p*, the flanging tools having been previously adjusted by the arrangement shown to the right of the engraving.

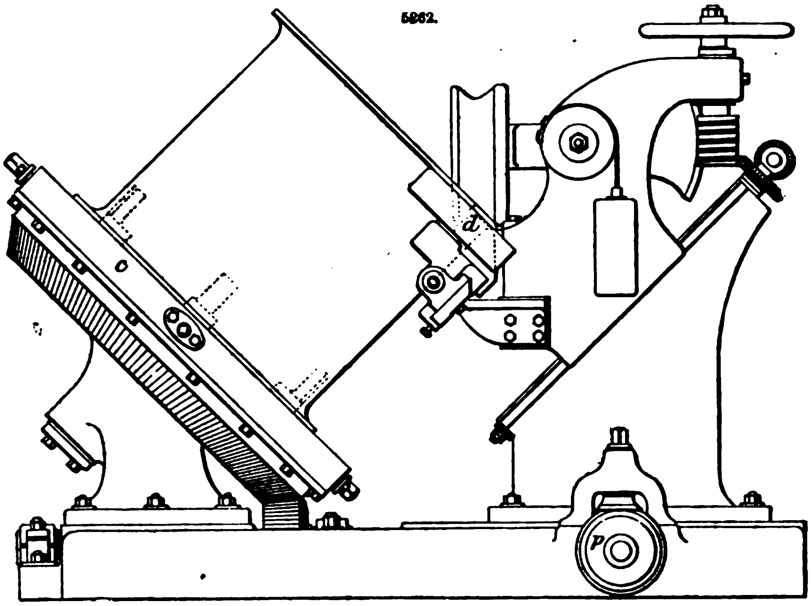
Figs. 5263 to 5271 are views of a set of machine tools made by Wm. B. Bement and Son, of Philadelphia, for railway purposes. The construction of Bement's machines is well worth careful attention, and we regret that, owing to circumstances, our illustrations do not sufficiently indicate the ingenious mechanism and extended applications of these important tools.

Locomotive-frame Slotting Machine, Fig. 5263.—This machine is intended for shaping the framing of locomotives in America, where such frames are made from rectangular bars in order to secure the needed strength, and yet be in a degree flexible. The side rails are fastened to the table *a*, along which the cutting mechanism is traversed by means of the rack and pinion seen on the side of the main frame.

The cutting movement corresponds to the Whitworth shaping machine, having a quick return and uniform forward motion. In American locomotives the bearings of the axles are fitted into

crotches formed in the frames, and these crotches have angular faces with a wedge to compensate or wear. To slot or shape these crotches or pockets an angular movement of the tool across the

5262.



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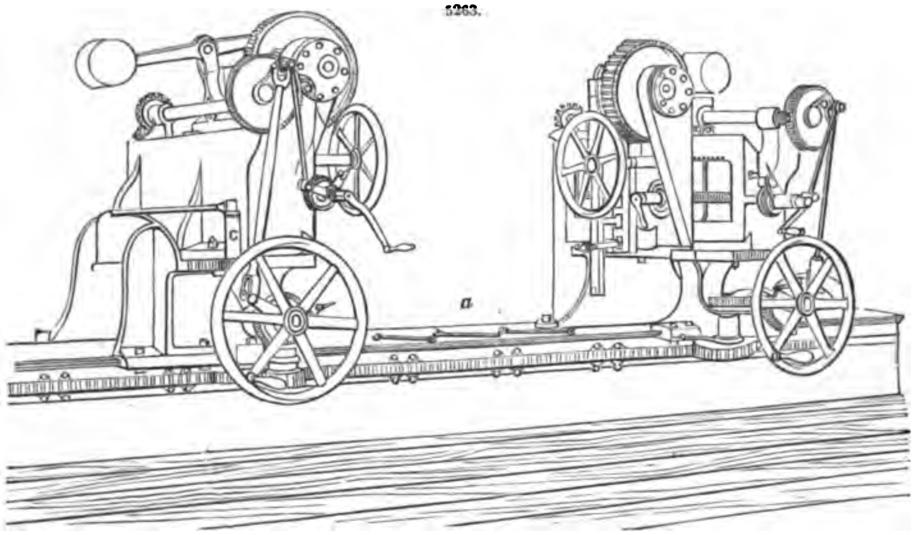

bed is needed; this is obtained by swinging the cutting head to the required angle by means of the rack and pinion seen at *c*. The head is provided on the axis of the vertical driving shaft that communicates motion to the cutter-bar. The driving pulleys are 30 in. diameter and 6 in. face, length of stroke, 12 in.; 24 ft. bed; and 16½ ft. between tools.

Bolt Threading Machine, Fig. 5264, intended for threading screws of all kinds used in bridge-building, railway carriage work or other uses to 2 in. diameter. The revolving head contains the dies, which are closed and opened while the machine is running in one direction by means of a friction-clamp operated by the lever seen on the front at 2; by revolving the dies a bolt or rod of any length can be threaded on a short machine, and by having the dies to expand or open while the machine is in motion no running back is necessary.

The clamping frame at *a* is moved on the top of the frame by means of the winch and bevel gears, and a rack and pinion below. The holding dies are closed and expanded equally from a centre. so that no adjustment is needed in changing for bolts of different sizes.

Axle Lathe, Fig. 5265, to turn the bearings, and wheel fits on railway axles. Length of bed, 11 ft.

The lathe is driven by cone with three changes for a 4-in. belt, and strongly geared; this is all that is necessary, as the work is nearly of a uniform diameter.

The feed is automatic, with two changes, operated by a handle attached to the carriage.

The bed is raised in front in order to secure additional strength, to shorten the tool-rest, and to allow the carriage to pass the sliding head; there being but one joint between the tool and the saddle.

The carrier is double, and self-adjusting; the dead spindle clamped by an improved binder consisting of a conical sleeve which adjusts to the wear of the spindle and keeps it central.

The counter-shafts are furnished with two sets of tight and loose pulleys to change speeds for roughing and finishing. There is a water-tank attached to the carriage, and tool closets to the standards.

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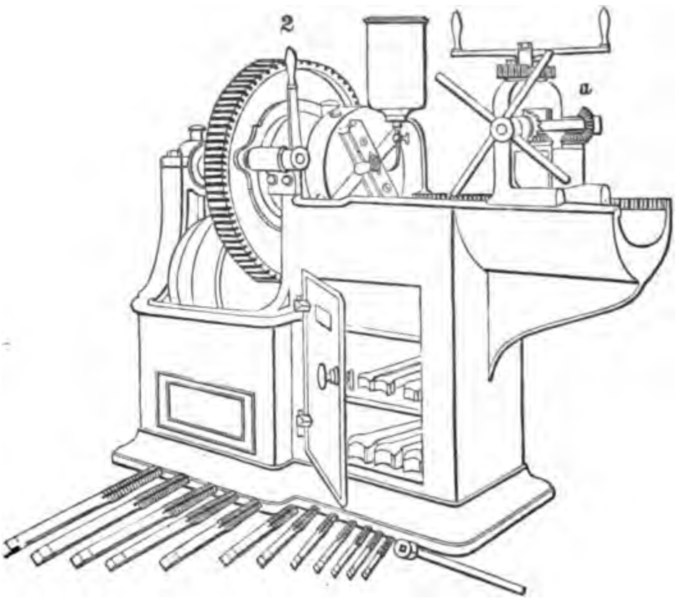

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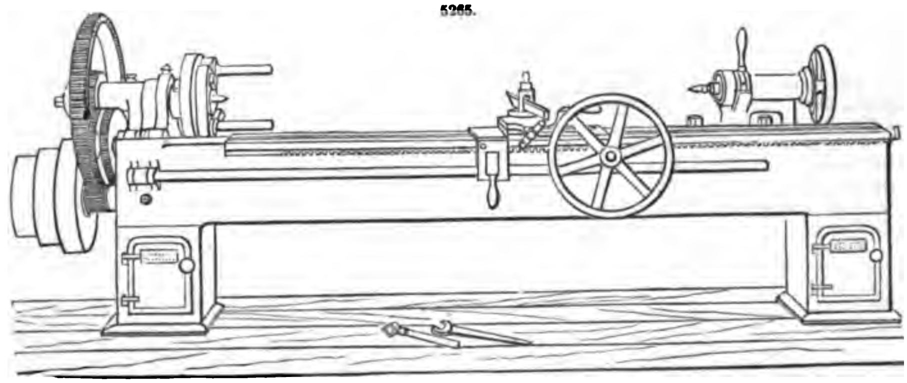

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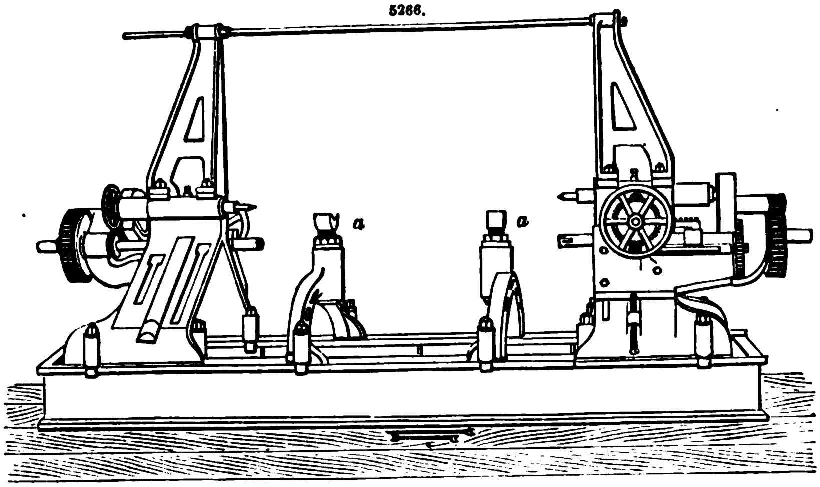
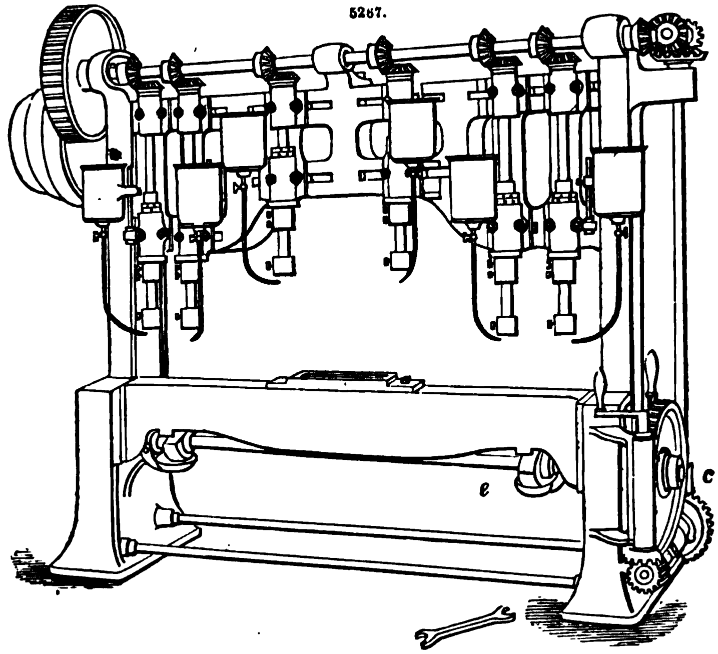


Wheel Quartering Machine, Fig. 5266, for boring the holes for the wrist-pins in both drivers of a locomotive engine at the same time, after they have been keyed to the axle. The axle is mounted

between the centres, as in a turning lathe, and the bed is 14 ft. long. The angular fans on which the boring frames are mounted are planed accurately to an angle of 45°, and the boring spindles

5267.



are moved up or down on the heads by means of screws, to suit the radial length of the crank and the stroke of the engine.

This arrangement of the whole mechanism and axle supports on one frame ensures not only that the cranks shall stand at right angles, but that the holes shall be bored parallel to the axle.

The two stands are to support the axle while mounting it, and to adjust it to the centres. The supports *a a* are to support the axle and wheels in mounting and removing them from the machine.

Multiple Drilling Machines, for Truck Irons or Braces, Fig. 5267.—Truck irons are bent before drilling to a shape indicated by the position of the lower end of the spindles. The bed or platform C is raised by cams seen beneath, and feeds the work up to the spindles, so that six holes are bored at the same time and in the proper position without laying out.

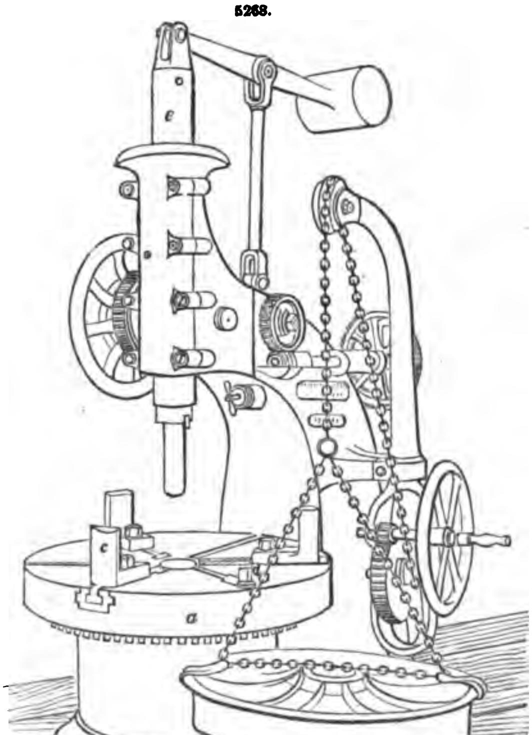
These braces were formerly punched, but their strength was found to be so much impaired by the operation that drilling had to be resorted to.

The feed-motion is connected from the top shaft by the vertical one seen on the right operating the tangent-wheel *c*, which is keyed to the cam-shaft *e*.

Wheel Boring Machine, Fig. 5268, intended for boring cast-iron car-wheels, the only kind used in America. *a* is a running table, or face-plate, having an opening below for chips, and driven by a bevel-gearing beneath. It is supported on a Schiele bearing that has a diameter at the top equal to half that of the table.

The jaws *c* are mounted on sliding

5268.



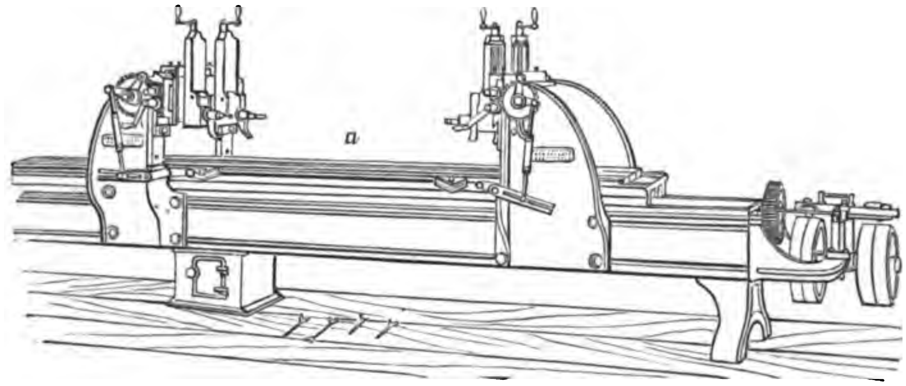
pieces fitted into the face-plate, and when fastened are all moved consecutively by means of a volute ring beneath the plate operated by the square shank *d*. The cutter-bar *e* is of cast iron, of large diameter, to secure rigidity, and is fed down by means of a rack at the back and the gearing seen on both sides of the main frame.

The wheels are loaded and unloaded by means of the crane at the side.

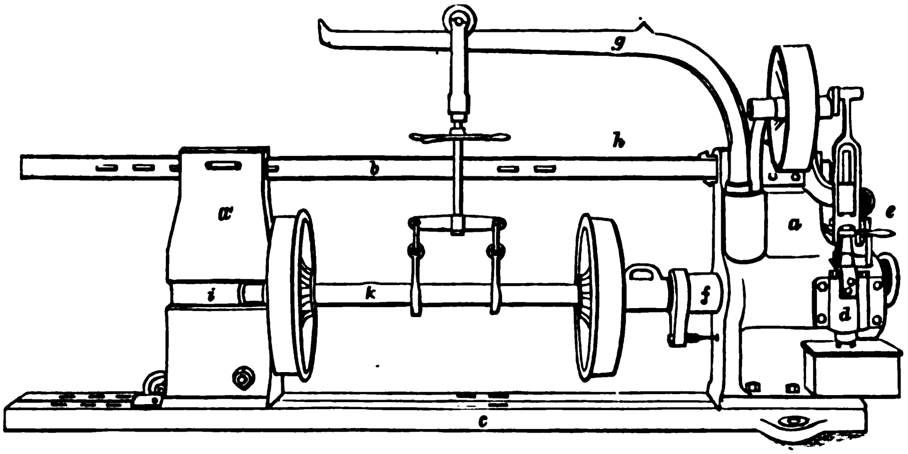
Compound Planing Machine for Connecting-rods, Fig. 5269.—The table *a* is moved at a uniform speed each way by means of a screw beneath and the ordinary reversing gearing seen at the end at *b*. The tools at each end act as the table moves backward and forward, which with four tools acting, quadruples the work of an ordinary machine using one tool.

The uprights with the cross-heads are moved to any part of the main frame to suit the length of the pieces to be planed. The cutting is performed alternately at each end of the piece, two or more tools acting at the same time.

5269.



5270.



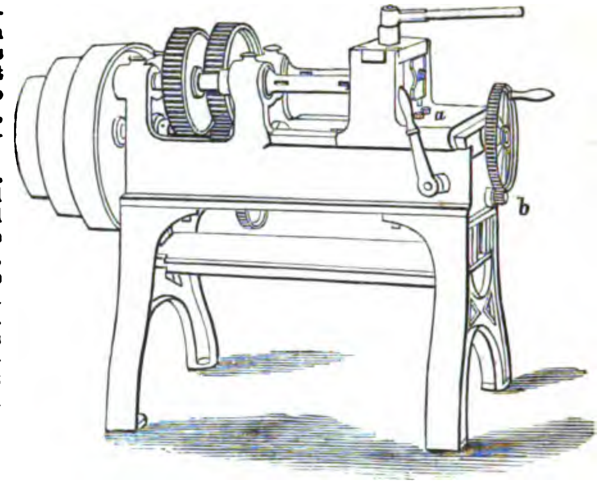
Hydrostatic Wheel Press, Fig. 5270, for forcing on or off the wheels of railway cars. The frames *a a* are connected by a strong strut *b* at the top, and by a cast-iron sole plate *c* at the bottom. The pump at *d* is fitted with a compound piston, one of ·75 in. diameter, fitting through a larger one of 1·75 in. diameter, so that either may act at will by turning the handle at *e*. In starting the piston *f*, and until it comes in contact with the work, the larger piston is used to secure a more rapid movement, and thus save time; the larger piston is then stopped and the smaller one set in motion to secure the required power.

The frames *a a* stand in position sufficiently inclined to allow the crane *g* to swing the axle *h* to a central position in the machine. To press off wheels the frame a^1 is moved to the position indicated by the slotted holes *h*, the axle fitting into the slot at *i*. This frame a^1 is mounted on rollers, so as to be readily changed as required for either putting on or taking off wheels.

Machine for Boring Axle-bearings, Fig. 5271, arranged to bore two at one time. The bearings are clamped by means of the screw and wrench seen on top. The saddle *a* is moved by a screw beneath, driven by the wheel and pinion at the end. The pinion *b*, below, is projected and withdrawn into the bearing to stop or start the feed by means of the handle in front.

Hydraulic Machine Tools.—Hydraulic power can in many instances be successfully and economically applied for working machine tools, which must then be specially arranged. Figs. 5272 to 5297 are of various hydraulic machine tools designed by Ralph Hart Tweddell, which as a whole are the best-planned hydraulic tools that have come under our notice. To a certain extent hydraulic power is best suited for heavy work, and for driving machines that have a rectilinear

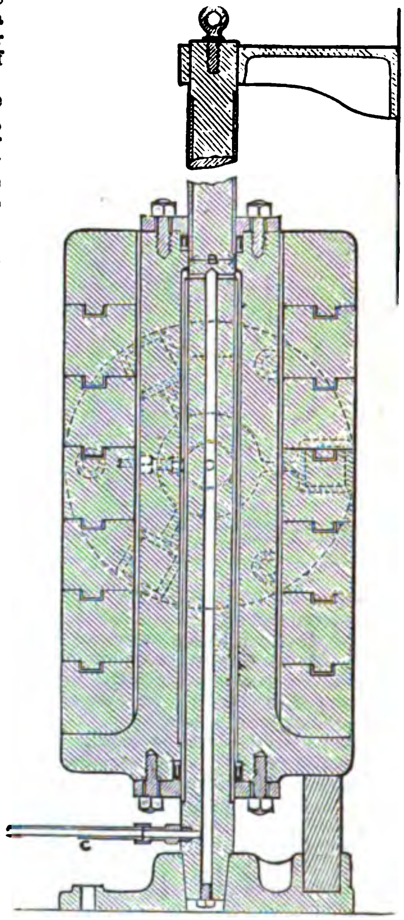
5271.



or a reciprocating motion, and would consequently not be suitable for such cases as shops in which a number of small lathes or other tools are employed; but this objection does not apply to the construction of iron ships, bridges, boilers, and similar descriptions of work.

As with Armstrong's system, p. 1963, the power is distributed by means of water conveyed through pipes, under pressure from a natural or artificial head, to the various machines to be worked by it. The pressure used by Tweddell varies from 1000 lbs. to 1750 lbs. a square inch; and as it is not generally possible or convenient to obtain even the lowest of these pressures from any natural head of water, it is obtained from an artificial head produced by means of a direct load or weight, against which the water to be used is pumped, the load thus producing the pressure that would be due to the elevation of a head of water. The accumulator by which this is effected consists of a loaded plunger or ram working in a cylinder, the water being pumped into the cylinder under the pressure of the load upon the ram.

5272.

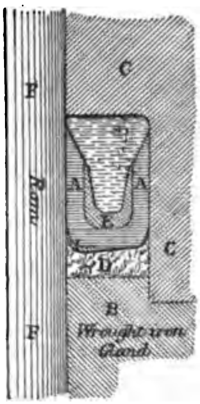


It is chiefly for intermittent requirements, as in the case of shop tools, especially those of the heaviest class, that the accumulator is of advantage; and little or nothing is gained by its intervention for doing any work of a continuous description, because in that case the engine would still be required to be of the same power as is now needed for performing the greatest amount of work that may be wanted at one moment. The principal ground upon which the use of water pressure supplied by an accumulator appears to be preferable as a means of distributing power is that the accumulator ceases to draw upon the engine when there is no useful work to be done, and thus saves fuel and power, together with the wear and tear that take place when an engine is always driving the gearing and shafting, although the machinery driven may not be at work.

The form of accumulator used by Tweddell, Fig. 5272, ensures a stiffness of spindle not otherwise to be obtained, and gives a compact arrangement for cases where so small a quantity of water is required as for supplying, say, only a single riveting machine. The ram or spindle B of the accumulator is here fixed, and acts as a guide, while the cylinder slides upon it, and is loaded with the weight necessary for giving the required pressure to the water. This plan of accumulator, although not new, possesses several good features. The water is pumped in at the bottom at C, and fills up the annular space surrounding the spindle; and the whole weight has to be lifted by the water acting only on the shoulder of the spindle, which is made by a brass bush ½ in. thick all round the spindle. A compact arrangement is thus obtained, and any required cubic capacity can be had by lengthening the stroke. The accumulator is supplied by two pumps, each 1⅜ in. diameter and 3¼ in. stroke, running at about 100 to 120 revolutions a minute. When the loaded cylinder B reaches the top of its stroke, it is made to close the suction-cock of the pumps, thus stopping the supply of water. When it is desired to put in a new packing leather at the bottom, the weighted cylinder is let down to rest upon blocks placed on the wood chocks at bottom, and the spindle is drawn up out of its tapered seat by an eye-bolt at top; for renewing the top-leather, the bracket holding the top end of the spindle has to be removed.

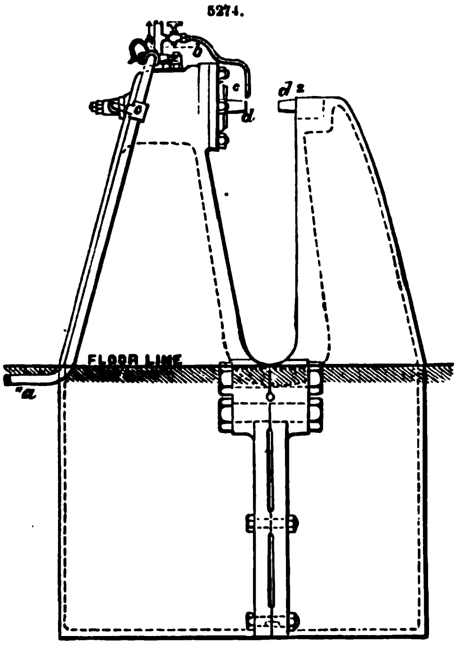
Fig. 5273 is a half-size section of the leather collar A A used for the accumulator, and for the hydraulic machines worked by it; the collar is secured by the gland B within the recess in the hydraulic cylinder C, a thickness of hemp bedding D being placed between the leather collar and the end of the gland. A brass cup-ring E is inserted within the collar to ensure keeping it open, or a gasket of plaited hemp is employed for the same purpose. At the part where the greatest wear of the leather collar would take place, from the friction of working against the ram or spindle F, a brass guard-ring I is added outside to protect the leather. The friction of the packing leathers and their wear and tear are a frequent cause of hesitation in adopting hydraulic machinery; but by using really good leather, and carefully moulding and fixing the collars in their places, and by giving proper attention to the wearing surfaces, and covering them with brass or gun-metal, as shown at I, more especially in those cases where the leathers themselves move, there is little trouble with the packing leathers. If the surface on which the leathers work is allowed to get dirty, they will become worn as fast as an ordinary engine slide-bar.

5273.

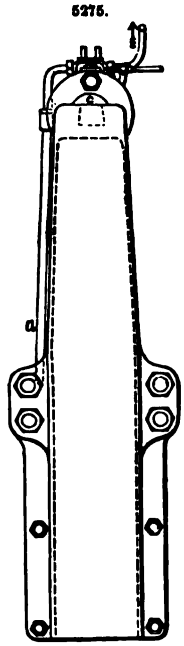


Figs. 5274 to 5279 are of one of Tweddell's fixed hydraulic riveters, made by Thompson and Boyd, of Newcastle-on-Tyne, by whom it has been worked with advantage for several years. Figs. 5280, 5281, show the letails of the valve-box and ram. The water from the accumulator is admitted to the cylinder and exhausted from it through the same aperture A, Fig. 5277, by means of a simple hydraulic valve of ordinary construction, shown in the sectional plan, Fig. 5280. The water enters at B, which tends to keep the inlet-valve C shut, the spring D also doing this until

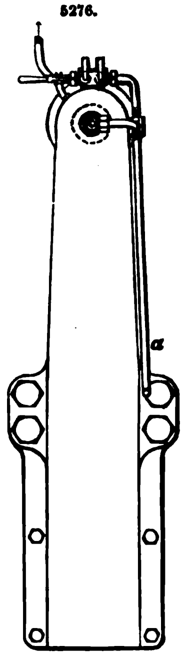
5274.



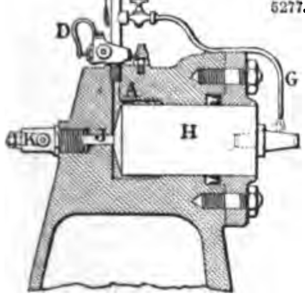
5275.

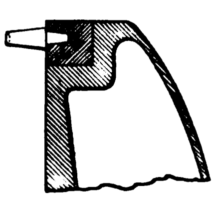


5276.

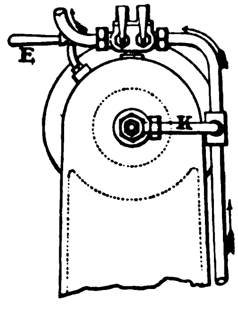


5277.

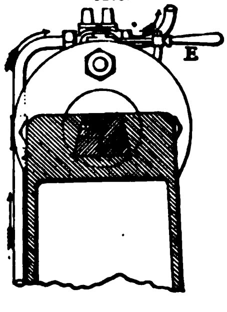




5278.

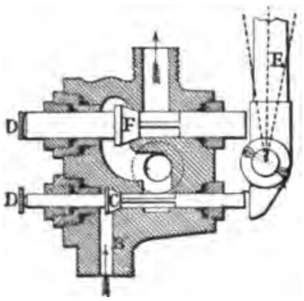


5279.

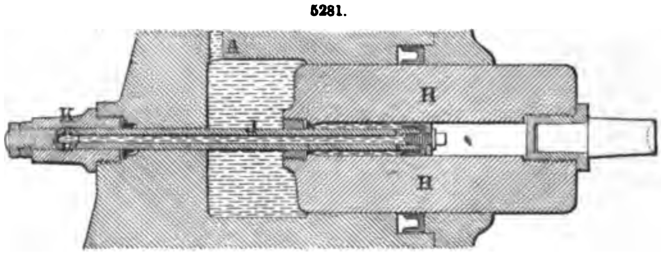


the pressure from the accumulator begins to act. When the water is to be admitted to the cylinder, the valve C is opened by the hand-lever E, and is kept open by hand until the rivet is closed, or

5280.



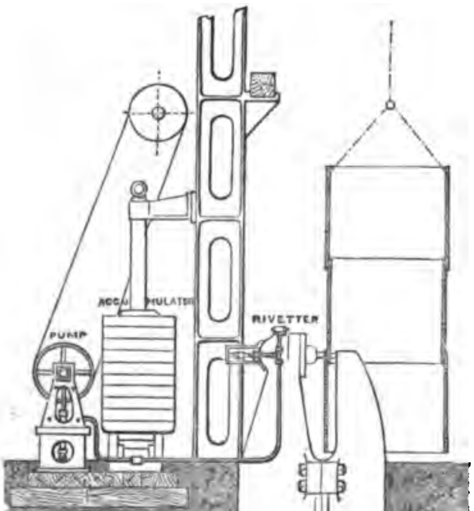
5281.



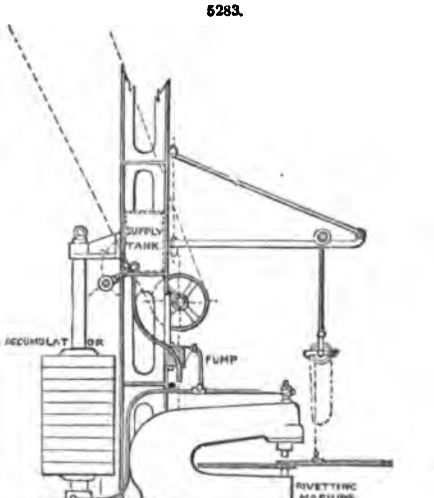
it is wished to stop the ram at any portion of its stroke. The exhaust-valve F is kept shut by the pressure of the water entering the cylinder, and at other times by the spring D. When it is desired to draw the ram back, the exhaust-valve F is opened by pushing the hand-lever over the reverse way to that for opening the inlet-valve C; this allows the exhaust-water to flow back to the pump-cistern, and a small portion of it is allowed to flow upon the die to cool it, through the pipe shown at G in Fig. 5277. The ram H is drawn back by means of the small drawback cylinder J, Fig. 5281, arranged within the ram itself and in constant communication with the accumulator through an inlet at K. The handle E unships readily, and is taken away by the operator whenever absent from the machine. By this plan of valves in combination with the drawback arrangement the greatest possible control is obtained over the machine, the ram being motionless as soon as the hand-lever is released or removed from the valves. The power of control thus obtained is of the greatest importance in riveting and punching, to prevent blind holes and unfair work; and it does away with all necessity for the care usually required in regard to the length of the rivets, as the machine shortens its stroke to suit a long rivet, while if the rivet is too short the machine still closes the plates equally well by extending its stroke. The wedge-shaped fastening of the die in the dolly, shown at L, Figs. 5277, 5279, obviates the necessity for any thickness of metal over the fixing pin ordinarily employed to keep the die in its place; this is of importance in extending the applicability of the machine in riveting flanged and angle-iron work.

In heavy work such as compound marine boilers this machine has put in 900 to 1000 $1\frac{1}{8}$-in. rivets in 1-in. plates in an ordinary day's work of ten hours; and portable boiler work at an average of seven rivets a minute. Fig. 5282 is one of these riveting machines arranged vertically for boiler and bridge work; and Fig. 5283 a horizontal arrangement for ship and bridge work.

5282.



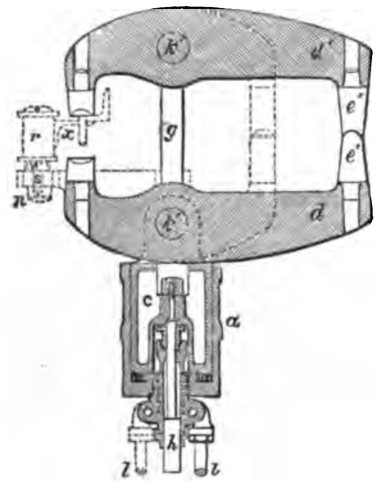
5283.



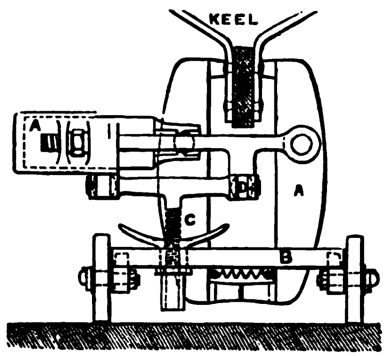
Figs. 5284, 5285, show the general features of Tweddell's portable hydraulic riveters, by Fielding and Platt, Gloucester. The ram c working in cylinder a being forced out and drawn back by suitable valve-gear; when going out it carries the cross-head d forward until the riveting die closes the rivet. The strain thus caused is received by the two tension-bars g, and the

ball-and-socket dies e' act as a point of resistance. By using these horns a depth X of from 9 to 12 in. can be taken in. In the drawing it is shown riveting the frame of an iron ship. This arrangement also serves as a very effective punching press.

5284.



5287.



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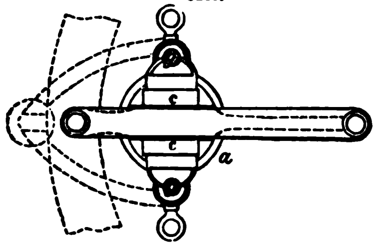
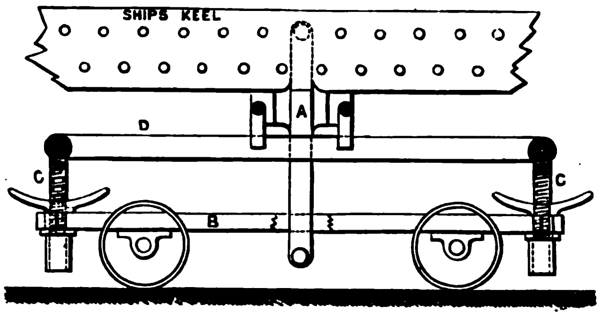
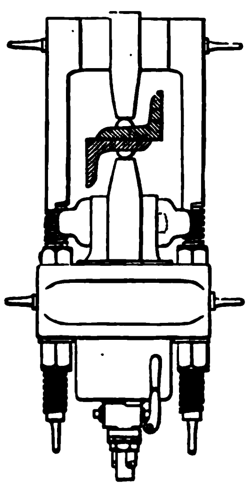


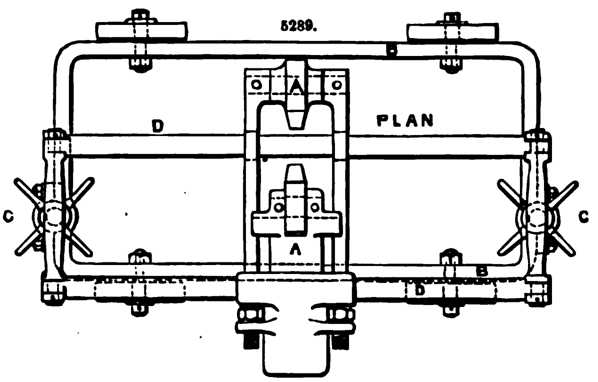
5288.



5286.



5289.



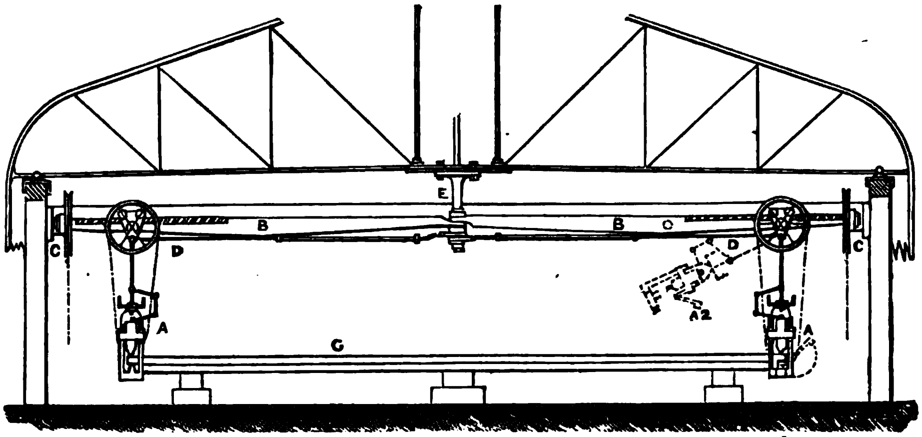
The weight of this machine varies from 2½ to 3 cwt. complete. Fig. 5286 is of another form of the portable riveter, without the cross-heads, the dies here being in line with the ram.

Figs. 5287 to 5289 illustrate the application of the portable riveter to riveting ships' keels. A is the machine which runs along two bars D D, supported on elevating and lowering screws C C, and the whole is carried by a wrought-iron bogey on four wheels. By properly adjusting screws C C, a whole row of rivets, about 7 to 8 ft. long, can be made, and the row below afterwards.

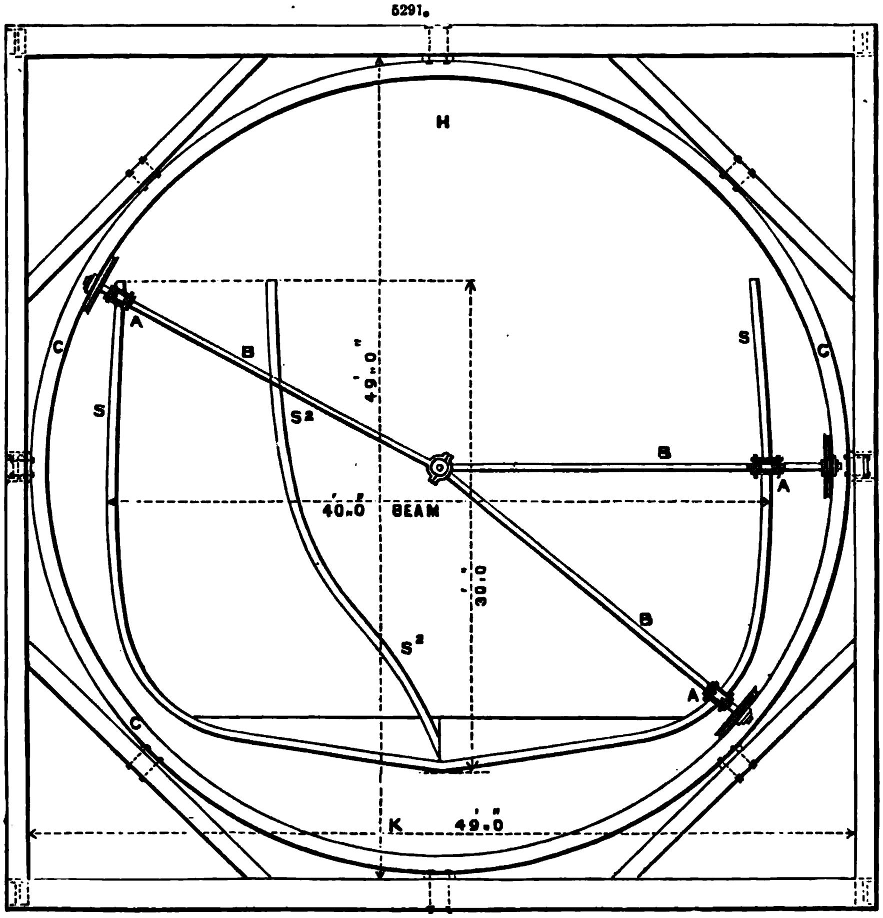
This machine is equally applicable to long girders, or any work too large to be brought to the machine.

Figs. 5290, 5291, show an arrangement of portable riveter for ships' frames. The system consists of a series of radial arms B, suspended from one communicator which contains a pipe from

5290.



5291.



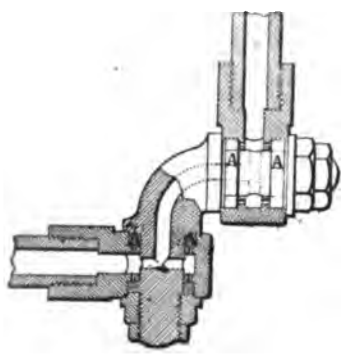
the accumulator E. These arms at their other extremity are supported on a circular rail C; it is evident that the portable machines *a a* suspended from these arms, and arranged by suitable rack and pinion, and telescopic pipes, can reach work placed anywhere within the circle of C. It

will thus be seen how they can quickly rivet up a frame, for instance, of an iron vessel, either of square section, as at S, or of finer section, as S_1. The frames would come in at H, and pass out finished at K at the head of a vessel being built.

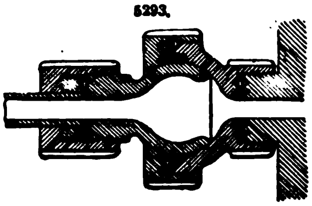
For any description of work this system answers equally well, and any modification of crane may be used instead of the plan shown in the figures.

Universal joints are used in these portable machines. Fig. 5292 is a double right-angled joint, and Fig. 5293 a ball-and-socket joint adapted for the purpose.

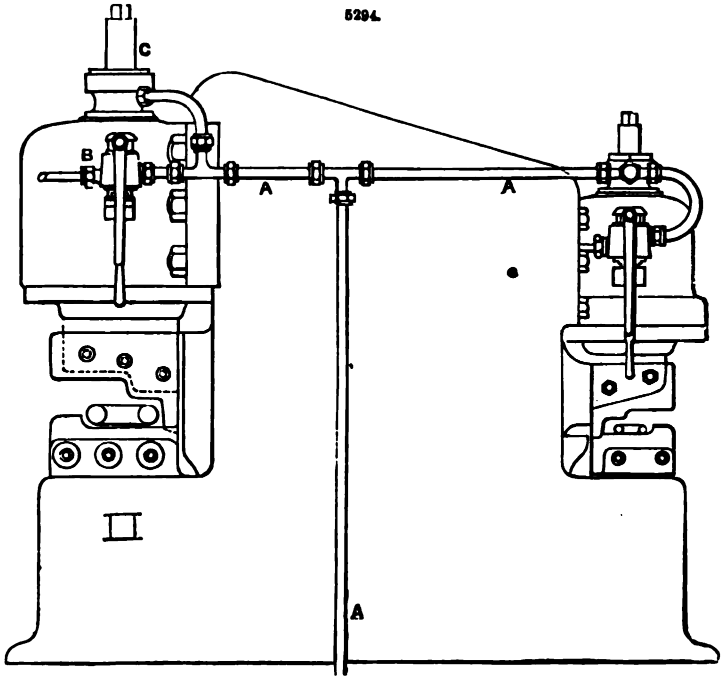
5292.



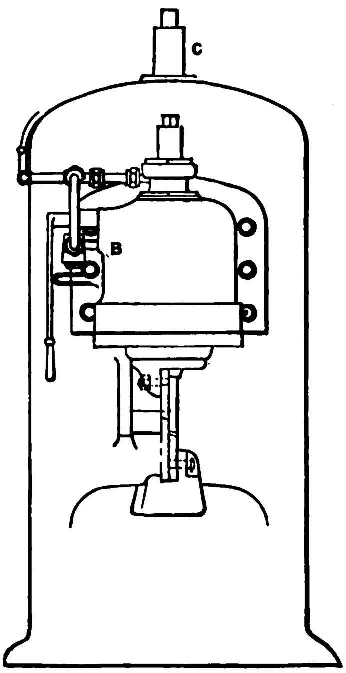
5293.



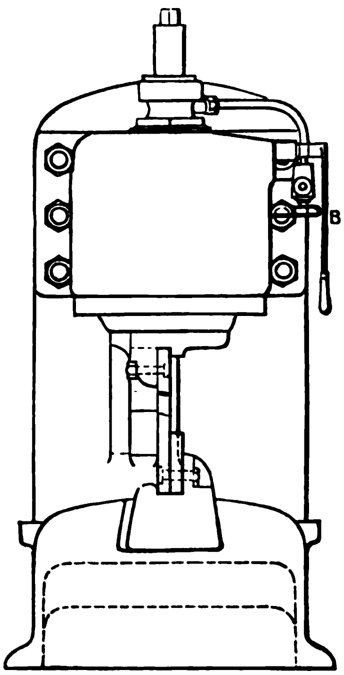
5294.



5295.



5296.



Figs. 5294 to 5296 are views of a hydraulic shearing machine for cutting cable chains. By a very simple modification the knives can be placed as in ordinary plate-shearing machines, and the other cylinder used as a punch. The machine is in some cases fitted to act as a horizontal riveter as well, and has another cylinder in the centre for angle-iron cutting, and bar straightening or bending. The cylinder arrangements are similar to those employed in the riveter already described. The water from accumulator enters at A, through a valve at B, and C acts as the draw-back or reversing motion.

5297.

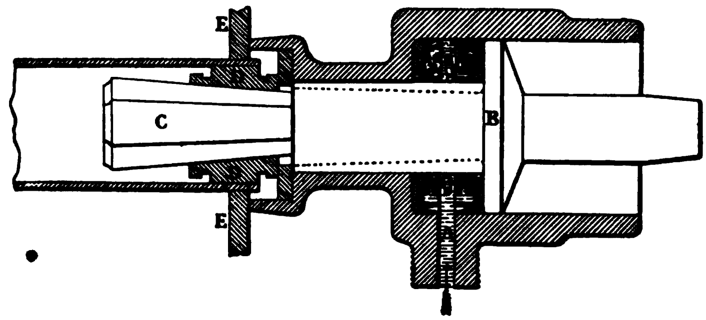


Fig. 5297 shows a hydraulic tube expander. The water is pumped in at A direct from a small hand-pump, and forces outwards the ram B, which draws the hexagonal wedge C through the dies D, thus expanding the tube in the hole in the tube-plate E. Upwards of sixty tube ends an hour can be finished by this tool, using a pressure of from 1¼ to 1¾ ton on the square inch.

See Hand-Tools. Hydraulic Machines.

MANDREL. Fr., *Arbre d'un tour*; Ger., *Drehbankspindel*; Span., *Mandril.*

A mandrel, or mandril, is a bar of metal inserted in the work to form it, or to hold it as in a lathe during the process of manufacture. Also the spindle which carries the centre chuck of a lathe and communicates motion to the work by a pulley; an arbor.

See Hand-Tools. Machine Tools.

MANGANESE. Fr., *Manganèse*; Ger., *Mangan, Braunstein*; Ital., *Manganeso*; Span., *Manganesa.*

Metallic manganese is obtained by calcining its oxides with carbon, a carburet of manganese being produced by the operation. This substance, when fused with a small quantity of manganous carbonate, gives the pure metal. This metal is sufficiently brittle to be reduced to a powder by trituration. Its specific gravity is 8·013; and it is almost infusible. At 212° Fahr. it readily decomposes water. As it oxidizes rapidly on exposure to the atmosphere, it should be preserved in naphtha, or in sealed tubes. Its atomic weight is 57; molecular weight unknown. The quantities of manganese entering into combinations are sometimes one, sometimes two atoms. Compounds containing only one atom are called minimum compounds, and those containing two atoms are known as maximum compounds. The minimum compounds are rarely saturated; the manganese in them nearly always acts as a bivalent. It is only in the maximum compounds that the tetratomic character of the metal appears. In this case, two atoms together form a hexatomic group, which could not be, unless we admit for each atom a maximum capacity of saturation equal to four at least. Quite recently, however, Nicklès has shown that manganese forms a chloride corresponding to the formula $Mn\,Cl_4$. Previously, it was found impossible to isolate this chloride, on account of its great instability. It may be decomposed into protochloride and chloride.

$$\underset{\text{Tetrachloride of manganese.}}{Mn\,Cl_4} = \underset{\text{Dichloride of manganese.}}{Mn\,Cl_2} + \underset{\text{Chlorine.}}{\left.\begin{matrix}Cl\\Cl\end{matrix}\right\}}$$

Nicklès succeeded in rendering it stable by combining it with the others. This chloride is produced and immediately destroyed when binoxide of manganese is acted upon by hydrochloric acid.

$$\underset{\text{Binoxide of manganese.}}{Mn\,\Theta_2} + \underset{\text{Hydrochloric acid.}}{4\left(\left.\begin{matrix}H\\Cl\end{matrix}\right\}\right)} = \underset{\text{Water.}}{2\left(\left.\begin{matrix}H\\H\end{matrix}\right\}\Theta\right)} + \underset{\text{Tetrachloride of manganese.}}{Mn\,Cl_4}$$

The existence of tetrachloride of manganese places the tetratomic character of this metal beyond a doubt.

The compounds of manganese with the monatomic radicals correspond therefore to one of the formulæ $Mn\,R_2$, Mn_2, R_6, or more rarely $Mn\,R_4$. The diatomic radicals also combine with manganese; the compounds correspond to the general formula $Mn\,R$ when they are minimum, and to the formula $Mn_2\,R_3$ when they are maximum. But besides this, and in consequence of the property possessed by the diatomic radicals of accumulating in indefinite numbers in the molecules, these radicals are capable of combining with manganese in proportions greatly superior in number to the two of which we have just been speaking. Thus four oxides of manganese are known—the protoxide $Mn\,\Theta$, the sesquioxide Mn_2,Θ_3, the red oxide $Mn_3\Theta_4$, and the binoxide $Mn\,\Theta_2$. Besides these,

two saline kinds are known, the manganates $Mn\,R_2\Theta_4$, and the permanganates $Mn\,R\Theta_4$. The anhydride corresponding to manganic acid would be $Mn\,\Theta_3$, and the anhydride corresponding to permanganic acid $Mn_2\,\Theta_7$. These two anhydrides are unknown; nor is the manganic acid $Mn\,H_2\,\Theta_4$ known; but, on the other hand, the permanganic acid $Mn\,H\Theta_4$ has been obtained dissolved in water, and it seems capable of existing in the solid state.

The protoxide is a basic anhydride; it dissolves in the acids, and forms minimum salts. It is obtained by causing a current of dry hydrogen to pass over binoxide slightly heated. The usual method of heating the binoxide is to place it in a proper vessel, and to fix it over a spirit lamp. Thus prepared, it will bear exposure to the atmosphere. A hydrate of manganese may be obtained by precipitating by an alkali a soluble minimum salt. This hydrate, when exposed to the air, becomes converted into a maximum hydrate.

The anhydrous sesquioxide is prepared by slightly calcining nitrate of manganese. This is a weak basic anhydride. When dissolved in the acids, it gives red and very unstable maximum salts; the sulphate, however, acquires stability in the presence of the alkaline sulphates with which it combines, forming salts that crystallize in the cubic system with twenty-four molecules of water. The double salt obtained with sulphate of potash should be expressed thus;—

$$\left.\begin{matrix} Mn_2 \\ (S\Theta_2)^3 \end{matrix}\right\} \Theta_6, \quad \left.\begin{matrix} S\,\Theta_2 \\ K_2 \end{matrix}\right\} \Theta_2 + 24\text{ aq.}$$

These salts, being isomorphous with those of alumina, have, from this circumstance, received the name of manganic salts of alumina.

The red oxide may be written $\left.\begin{matrix} Mn_2 \\ Mn \end{matrix}\right\} \Theta_4$. This compound is then considered as containing the manganese at the maximum and the minimum at the same time. It occurs native in *hausmannite*, and may be obtained artificially by igniting the sesquioxide or the binoxide in the open air. It is a compound of these two oxides.

The binoxide, $Mn\,\Theta_2$, exists in a native state, and constitutes by far the most abundant of the manganese ores. When heated with hydrochloric acid, it produces water and manganic tetrachloride, the latter of which is destroyed as soon as formed, by liberating chlorine; at the same time protochloride is produced. The solution of this chloride, when subjected to the action of an alkaline carbonate, gives a precipitate of carbonate of manganese, by the aid of which all the minimum salts of this metal may be prepared.

Manganate of potash, $Mn\,K_2\,\Theta_4$, is obtained by fusing together hydrated potash and binoxide of manganese, in contact with the air, or, better, by calcining binoxide of manganese with a substance capable of giving up potassium and oxygen, as nitrate of potassium. Manganate of potash is green. Alkaline water dissolves it without producing any change in its constituent parts, but pure water, or, better still, water to which a small quantity of nitric acid has been added, converts it into a mixture of hydrated peroxide of manganese and permanganate of potash.

$$\underset{\substack{\text{Manganate of}\\ \text{potassium.}}}{3\,Mn\,K_2\,\Theta_4} + \underset{\text{Water.}}{2\,H_2\,O} = \underset{\substack{\text{Binoxide of}\\ \text{manganese.}}}{Mn\,\Theta_2} + \underset{\substack{\text{Permanganate}\\ \text{of potassium.}}}{2\,Mn\,K\,\Theta_4} + \underset{\text{Potash.}}{4\left(\left.\begin{matrix} K \\ H \end{matrix}\right\}\Theta\right)}$$

When the solution of potassic manganate is exposed to the air, the carbonic anhydride produces slowly the reaction of which we have just spoken, and as the colours of manganate and permanganate of potash are very different, a great variety of hues are produced, and from this circumstance this substance was formerly called the *mineral chameleon*.

Permanganate of potash is obtained by the calcination of a mixture of peroxide of manganese, hydrate of potassium, and chlorate of potash. When the solution is filtered upon amianthus, and then evaporated in a porcelain vessel, crystals of permanganate of potash are thrown down, corresponding to the formula $Mn\,K\Theta_4$. Permanganates of potash with saline solutions of the metals give precipitates. Permanganate of baryta, thus prepared by double decomposition, gives off permanganic acid when acted upon by diluted sulphuric acid.

$$\underset{\substack{\text{Permanganate}\\ \text{of baryta.}}}{(Mn\,\Theta_4)^2\,Ba} + \underset{\substack{\text{Sulphuric}\\ \text{acid.}}}{S\,\Theta_4\,H_2} = \underset{\substack{\text{Sulphate}\\ \text{of baryta.}}}{S\Theta_4\,Ba} + \underset{\substack{\text{Permanganic}\\ \text{acid.}}}{2\,Mn\,\Theta_4\,H}$$

Under the influence of potash the permanganates are converted into manganates;—

$$\underset{\substack{\text{Permanganate}\\ \text{of potash.}}}{4\,Mn\,K\Theta_4} + \underset{\text{Potash.}}{4\left(\left.\begin{matrix} K \\ H \end{matrix}\right\}\Theta\right)} = \underset{\substack{\text{Manganate of}\\ \text{potash.}}}{4\,Mn\,K_2\,\Theta_4} + \underset{\text{Water.}}{2\,H_2\,\Theta} + \underset{\text{Oxygen.}}{\left.\begin{matrix} \Theta \\ \Theta \end{matrix}\right\}}$$

The permanganates of potassium, sodium, barium, strontium, and silver, are isomorphous with the perchlorates of the same metals. The soluble permanganates affect a beautiful violet colour.

Reactions of the Salts of Manganese.—The salts of manganese may be recognized by the following characteristics;—

1. They are rose-coloured, and become white when dried.
2. When heated upon a piece of platina with potash in the oxidizing flame of the blow-pipe, they give a green mass of alkaline manganate.
3. When boiled with a mixture of binoxide of lead and nitric acid, they give a liquor which is coloured violet by permanganic acid. This reaction is very sensible.
4. Potash and soda produce in them a white precipitate, which becomes rapidly discoloured on exposure to the air.
5. The soluble alkaline sulphurets determine in them the formation of a flesh-coloured pre-

cipitate of hydrated sulphuret of manganese. This precipitate will dissolve cold in weak hydrochloric acid.

Manganese is not easily produced by itself; it is extremely refractory, and has a strong affinity for oxygen. It may be produced by mixing one of its oxides with lamp-black and oil, and exposing it to the strongest heat in a coal-lined crucible. The metal thus obtained is not pure, it contains carbon. Manganese metal is soft and brittle; its sp. gr. is 7 or 8; it is very oxidizable, but slowly in cold, although rapidly in warm water, or acid water. It resembles iron, cobalt, and nickel, very much, and combines with these easily; which may be caused not so much by affinity as a similarity in properties—particularly in their relation to heat, and melting. On the other hand, it resembles very much the alkaline metals; and in respect to forming slag, the most important office it performs for the metallurgist, it ought to be classed with the alkalies. It does not occur native.

Ores.—There is but one ore of manganese which is of practical use to the metallurgist; and that is the binoxide, or black manganese. This is a black-brown, shining substance—amorphous—and contains, when pure, 63·6 per cent. of metal. The most valuable kind of this mineral is the crystallized variety, called grey manganese—pyrolusite. These ores are generally adulterated with iron, alumina, and quartz, and contain water; sp. gr. 4·8 to 4·88.

Alloys.—The only use made of manganese is in an alloy with other metals, particularly iron; and as it has a peculiar affinity for that metal, we observe it in most iron ores, and consequently in crude iron. It combines readily with phosphorus, carbon, or silicon, and forms with the latter substance an alloy which resists the attacks of aquafortis successfully. We may here observe that it is not the relation which the elements of an alloy bear to oxygen which causes it to resist the attacks of acids, but the compactness of the metal. Manganese is as oxidizable almost as potassium, and silicon is easily attacked by oxygen. A compound of the two is as durable as gold, and is not touched by the strongest acids. Manganese melts with all other metals, and causes hardness. It imparts to iron whiteness, and causes it to become hard and brittle. It is found in very small quantities in good steel, not often in wrought iron. A little iron in manganese improves its resistance to the attacks of oxygen, and causes it to be magnetic. We do not know if it may be combined with zinc, antimony, or lead, but suppose so, if the operation is performed under proper conditions.

Manganese is very refractory, and has a strong affinity for oxygen; its protoxide forms one of the most powerful bases in silicates with which we are acquainted—in fact, it cannot be reduced in the presence of silex. As the formation of slags is all-important in metallurgy, manganese becomes—if not as a metal, as an oxide—one of the most useful substances in smelting operations.

See Spiegeleisen. Steel.

MANSARD ROOF. Fr., *Comble à la mansard;* Ger., *Mansardendach;* Span., *Armadura á la mansarda.*

See Roofs.

MARINE ENGINE. Fr., *Machine à vapeur marine;* Ger., *Schiffsdampfmaschine;* Ital., *macchina marina;* Span., *Máquina marina.*

Marine engines were first introduced in the year 1828, and amongst the early machinists Fulton, Miller, Penn, and Rennie may be mentioned as having been the most instrumental in bringing the arrangement to its present state. The illustration, Fig. 5298, represents the end elevation of the modern oscillating paddle-wheel engines, fitted by Ravenhill, Salkield and Co., in H.M. ships Helicon and Salamis. The air and feed pumps are shown in section to illustrate the relative positions of the suction and discharge valves, and the points from which the motion is obtained; this for the feed-pumps is from an arm secured to the cylinder, and for the air-pump from a crank-pin formed with the intermediate shaft. The front and sectional elevations are shown by Fig. 5299. The sectional part shows the cylinder, steam-pipe, entablature, disengaging disc, connecting rod, and crank in section. The complete part, the air-chamber, starting gear, hand-rail, platform, and bilge-pump pipes, valve-casings, expansion-gear, trunnions, steam-pipe, entablature, and cylinder cover and connecting-rod head. Fig. 5300, the plan in sectional and complete views of the same number of details as before. Fig. 5301, the cross stay-frames, columns, expansion-cam, and gear, steam branch-pipe, pumps, and lower frame, and the entablature, disengaging disc, and hand steam-valve gear. Fig. 5302 illustrates the starting gear, which is of the balance eccentric class, with the sliding quadrant levers and single-ported slide-valves. The action of this gear is such that, when in the position shown, the hand-wheel is disengaged and the valves are worked by the eccentric; but on pushing the eccentric-rod off the quadrant-pin by the hand-lever above the wheel, the valves are motionless, and can be then hand-worked by pushing the hand-wheel pinion in gear with the quadrant-rack.

Fig. 5303 gives four views of the cylinder, which is in one casting, and arranged for two slide-valves—one on each side of the inside trunnion bearing, for balancing. Fig. 5304, two views of the cylinder cover, gland and stuffing box fitted with a deep wearing-bush. Fig. 5305 shows the piston in two sectional views, the packing used behind the spring-ring is the usual gasket.

Fig. 5306, the slide-valve casing; it is shown by three views, and the main feature in it is the passage in the frame and cover that communicates the back of the slide-valve with the condenser, so as to take away any back pressure of steam as well as the steam pressure from the face.

Fig. 5307 illustrates the slide-valve, which is an ordinary single-ported valve, packed at the back with a six-bar spring, that presses a ring against the casing cover, and thereby prevents the steam from acting on the back of the valve.

Fig. 5308 is the elevation of the starting or reversing gear, and shows the eccentric-rod in connection with the sliding quadrant.

Fig. 5309, the plan of the starting wheel, shaft, bracket, hand-lever, and box-spring.

Fig. 5310, a sectional plan of the reversing gear in connection with the cylinder, and shows the levers and sliding quadrant with their pins.

5298.

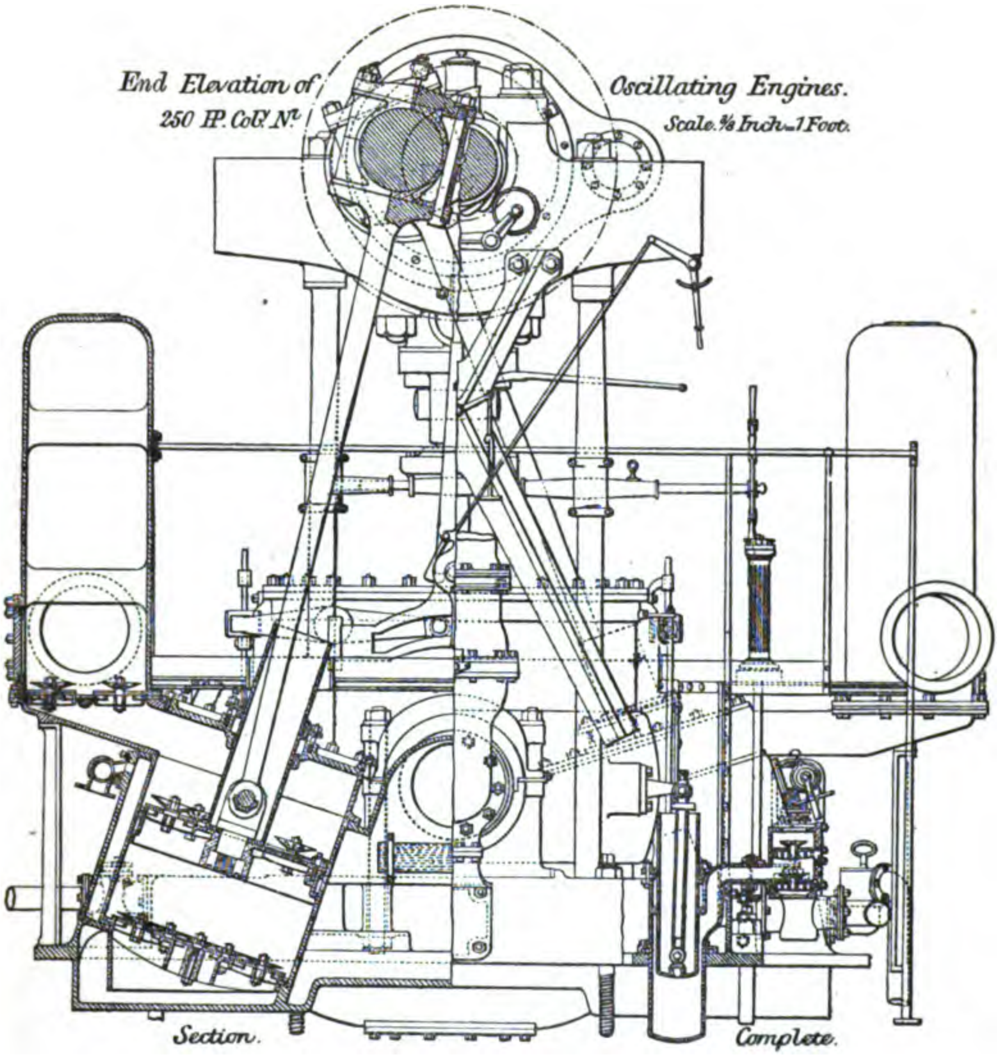


Fig. 5311 is of a set of details of the eccentric-rod lever and pin; and Fig. 5312 are the levers for working the slide-valves.

Fig. 5313, the details of the valve-rods and pins; and Fig. 5314 is the guide for each rod.

Fig. 5315, the details and working-gear sweep, also called the sliding quadrant.

Fig. 5316, the starting rack that is secured to the quadrant; and Fig. 5317, the bracket that supports the starting shaft.

Fig. 5318 illustrates that shaft, also the wing and midship columns.

Fig. 5319, details of the eccentric and counterbalance or balance-weight, as well as the eccentric-band.

Fig. 5320, the expansion-gear, side frame, and valve-casing, and bracket to which it is connected.

Fig. 5321, the carriage cam-wheel and grade-pin; and Fig. 5322, the expansion-rods and release-lever in connection with the release-rod shown to the right of the same figure.

Figs. 5323, 5324, illustrate the spring-boxes for the eccentric-rod and the cam-rod.

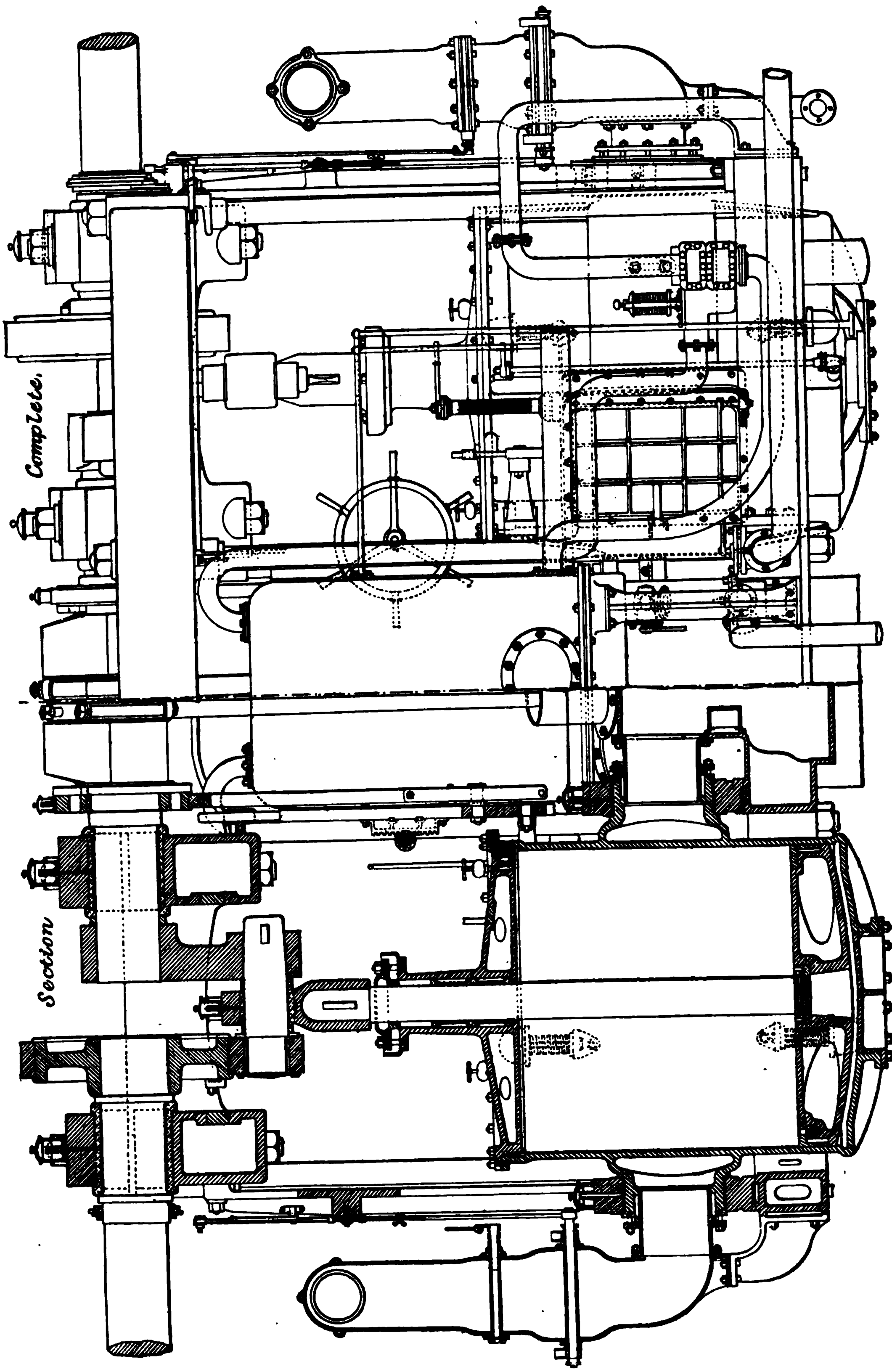
Fig. 5325, the expansion-valve and casing; Fig. 5326, the lever for the valve-spindle; and Fig. 5327, the gear-brackets and sweep-block.

Fig. 5328, two views of the expansion-valve casings and bracket.

Fig. 5329, the stop-throttle valve and seat; and Fig. 5330, the steam throttle-valve gear.

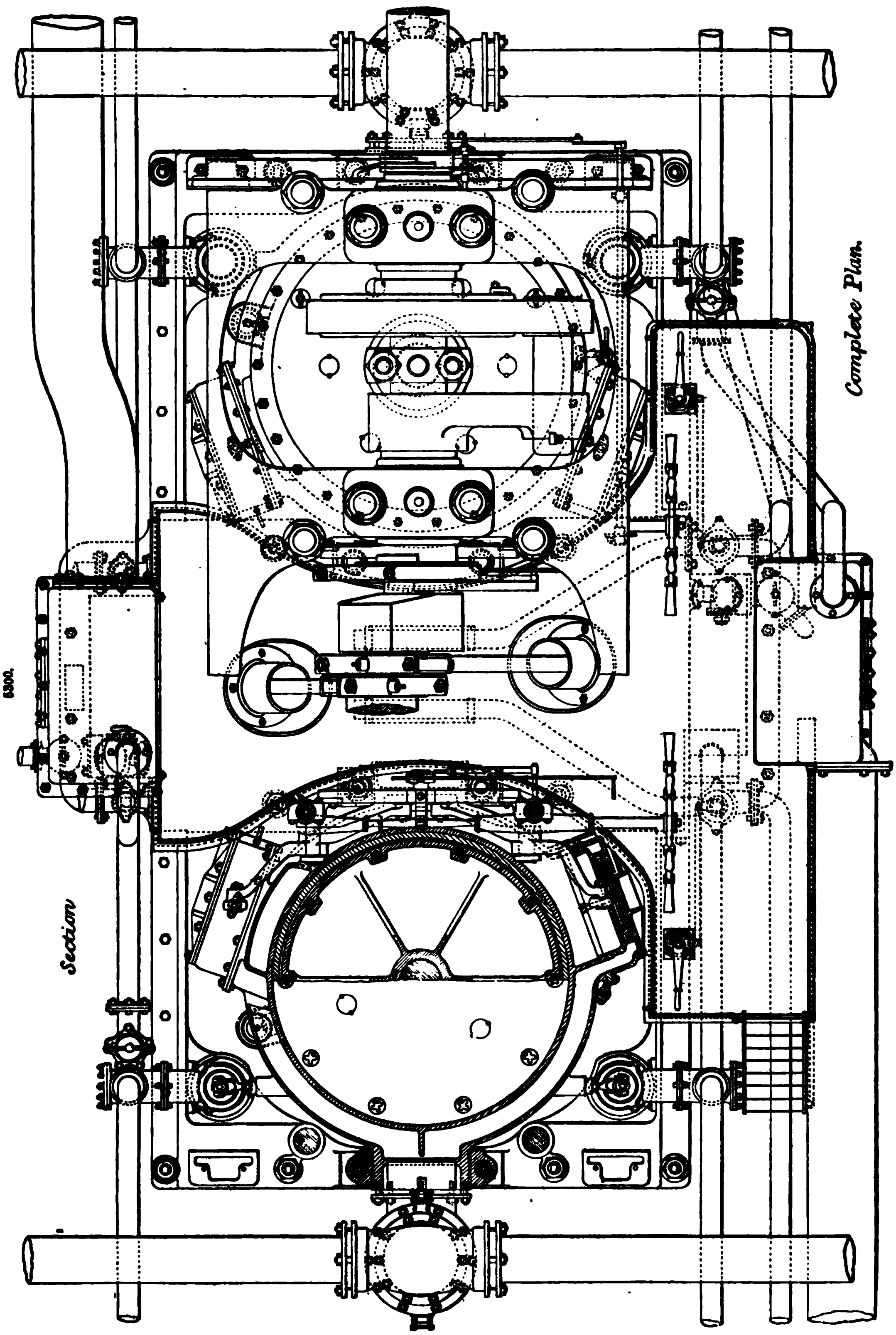
Fig. 5331 illustrates the arrangement of the air-pumps and condenser in sectional and complete views, also showing the connecting rods in a similar manner.

Fig. 5332 shows three views sectional and complete of the condenser alone, and also the passages, projections, and openings requisite according to the arrangement of the engine.



5299.

Front Elevation.



Complete Plan.
Sectional Plan.
5300.
Section

5202.

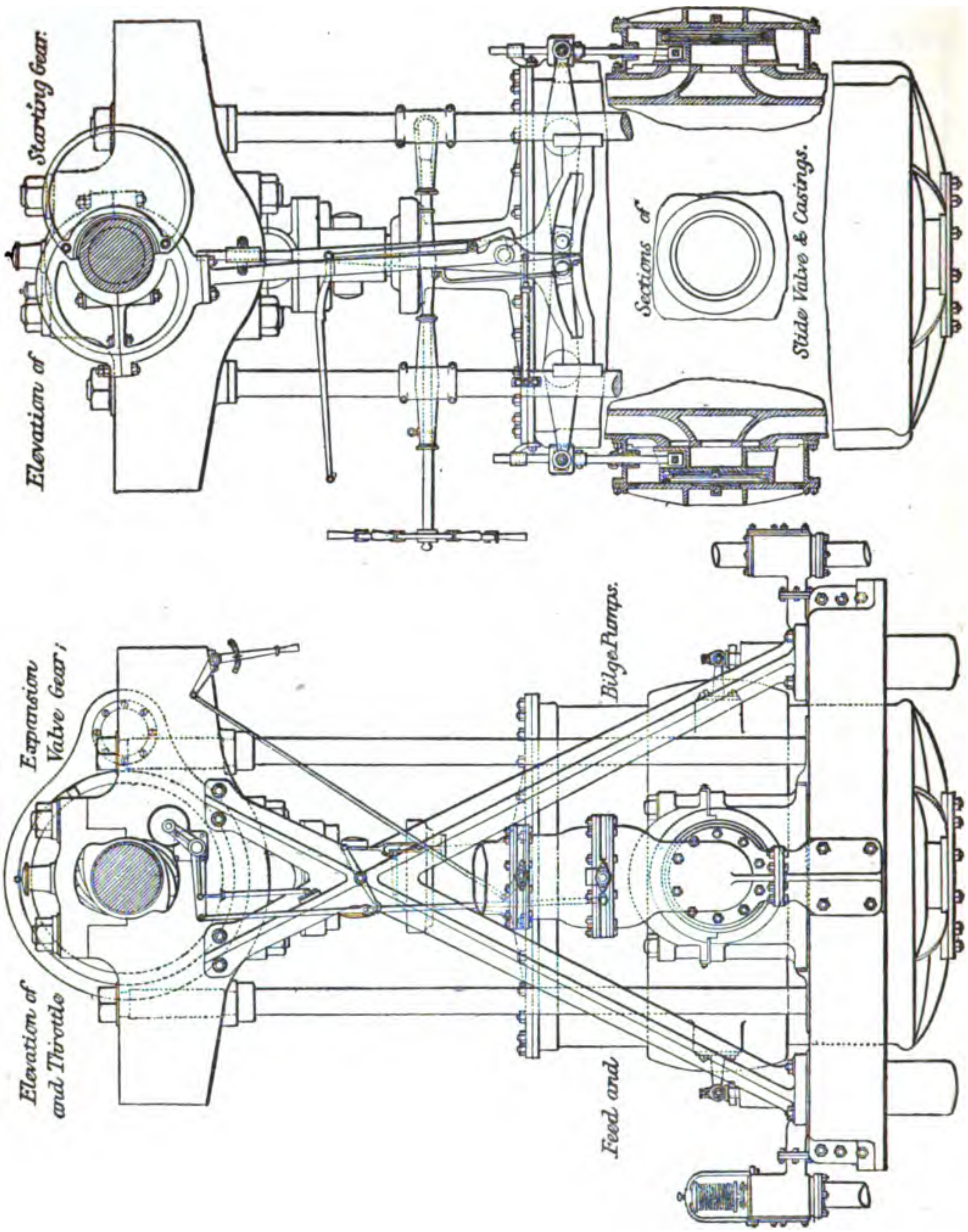


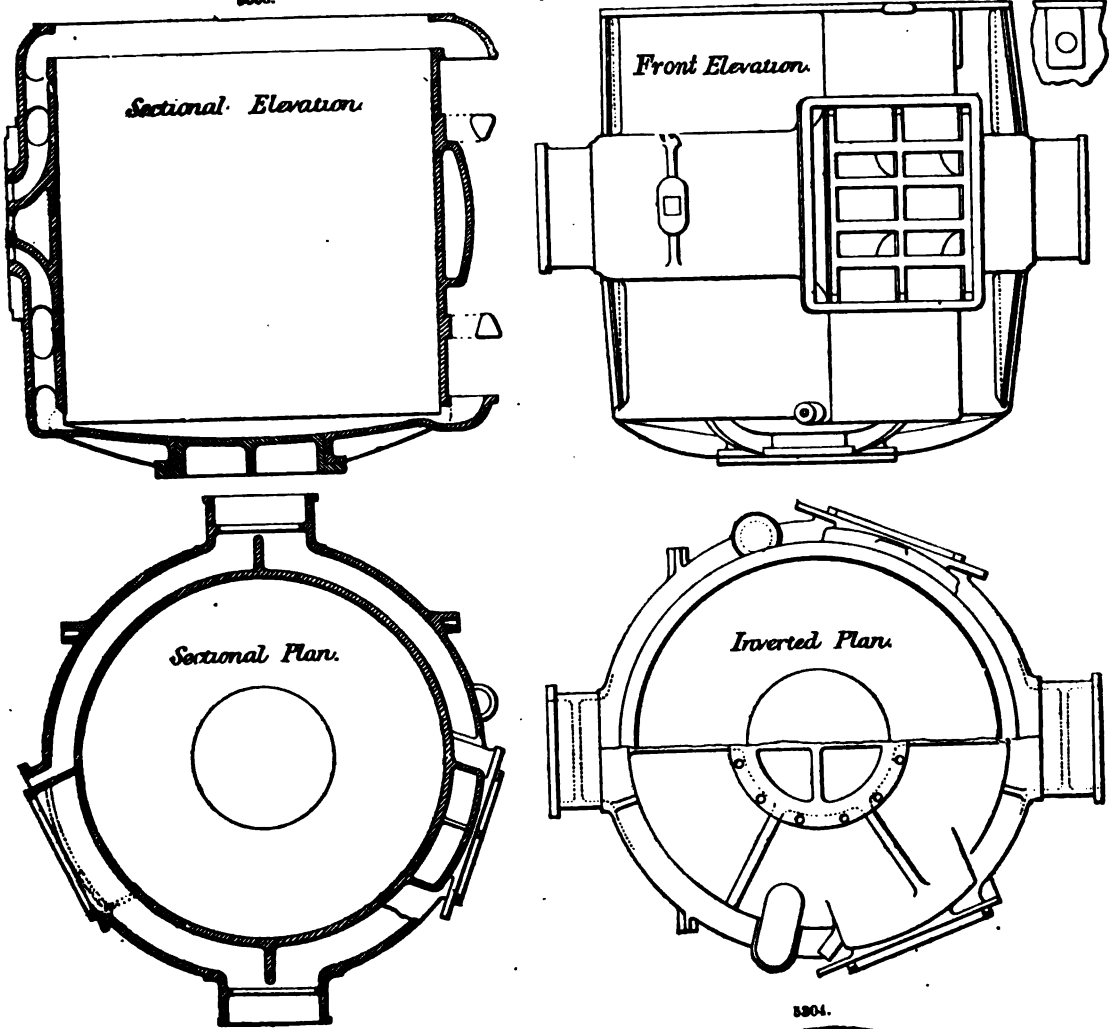
Fig. 5333 is a sectional elevation and plan of the branch piece that forms the discharge passage and the seating flange of the discharge-valve plate and air-chamber. Fig. 5334 is a section and plan of that plate and valves; and Fig. 5335, the air-chamber that covers them, often termed the hot-water cistern.

Fig. 5336, the suction or foot-valves and seat; and Fig. 5337, the piston and valves, sometimes termed the air-pump bucket.

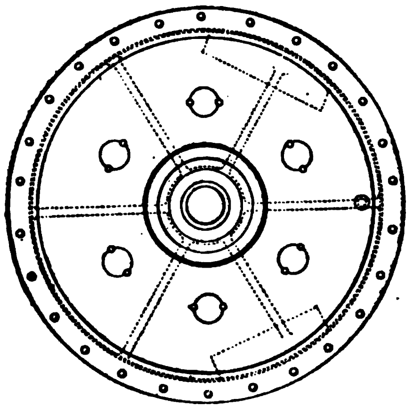
Fig. 5338, the air-pump, trunk, and rod's connection; and Fig. 5339, the connecting rod, crank, end head, cap, bolts and nuts.

Fig. 5340, the sea injection-cock, to admit water into the condenser to condense the steam; and Fig. 5341 is the gear used for regulating the admission. Fig. 5342, the kingston-valve and casing, that admits the sea-water through the ship's bottom to the injection-cock.

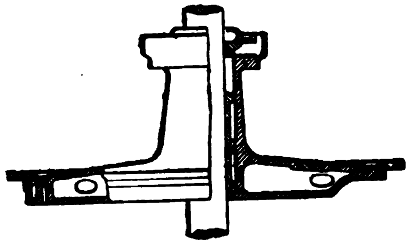
5303. Cylinder.



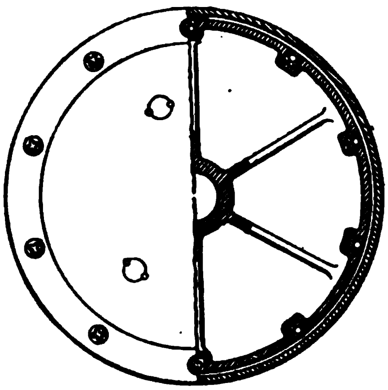
5304.



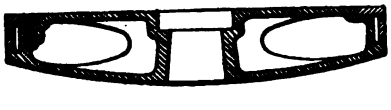
Cylinder Cover.



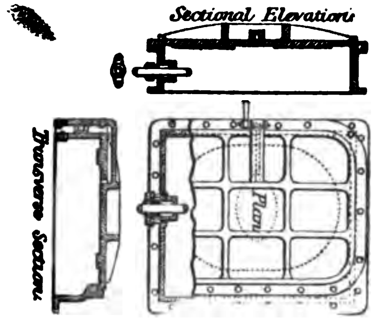
5305.



PISTON.

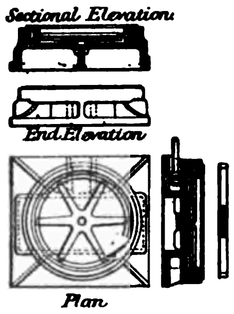


5306.



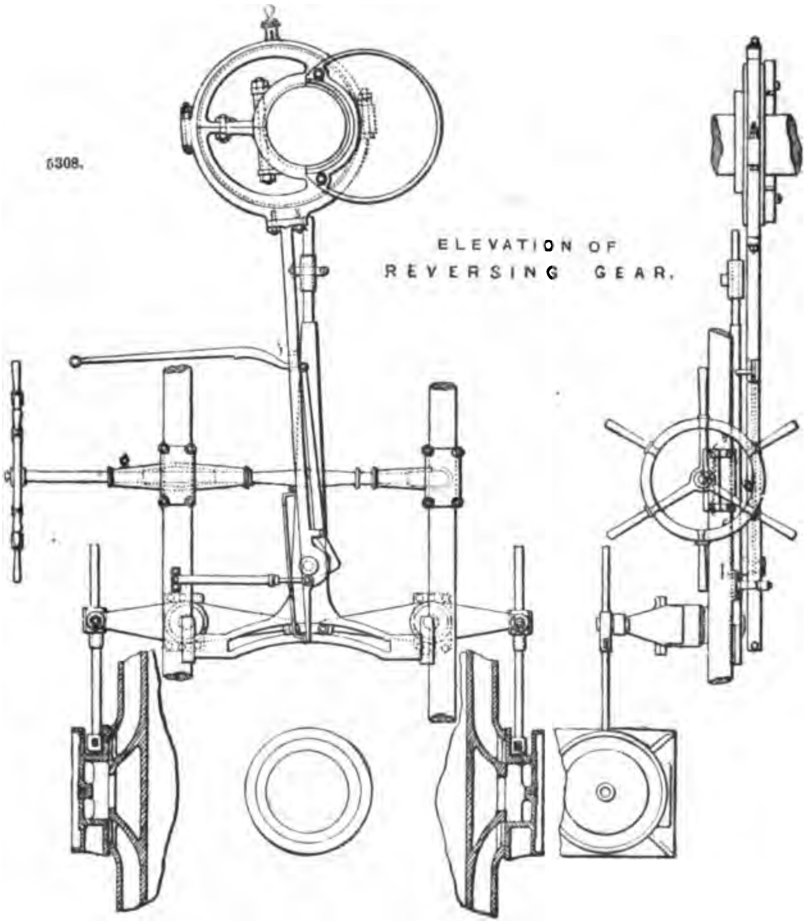
Slide Valve Casing.

5307.



Slide Valve.

5308.



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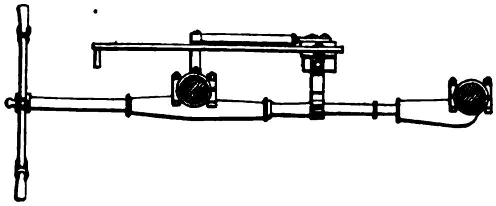
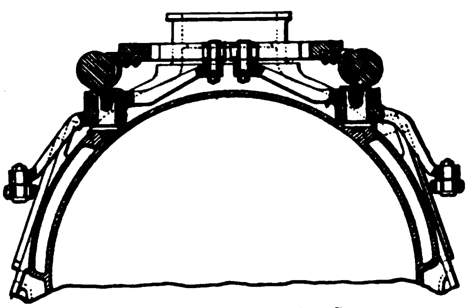
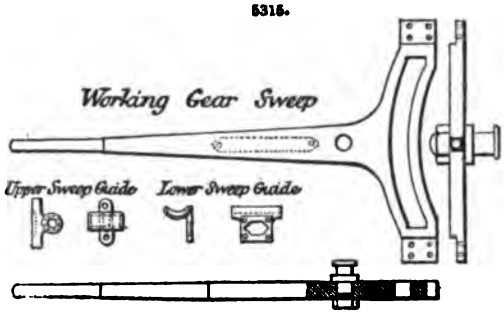


5310.

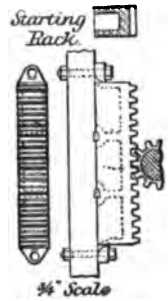


Sectional Plan of Reversing Gear.

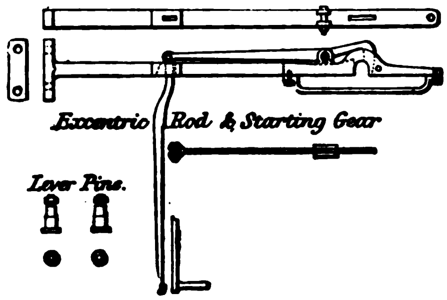
5315.



5316.



5311.



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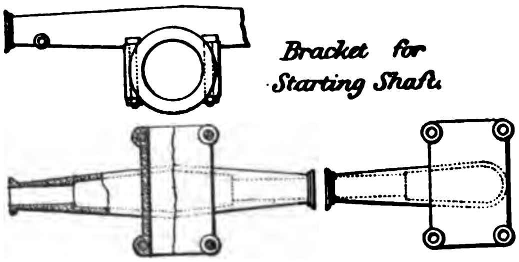

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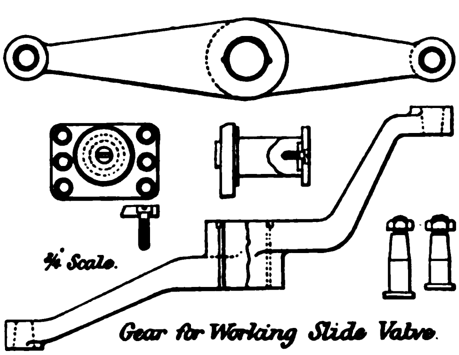
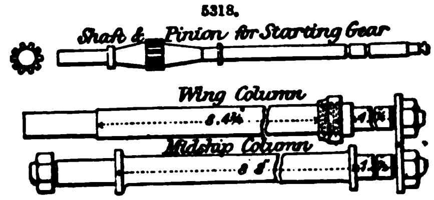


5318.



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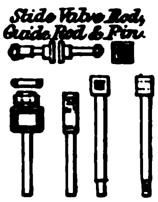
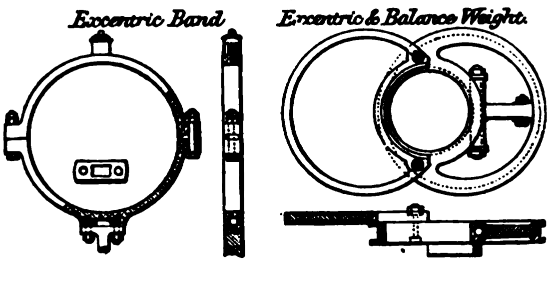


5314.

5319.



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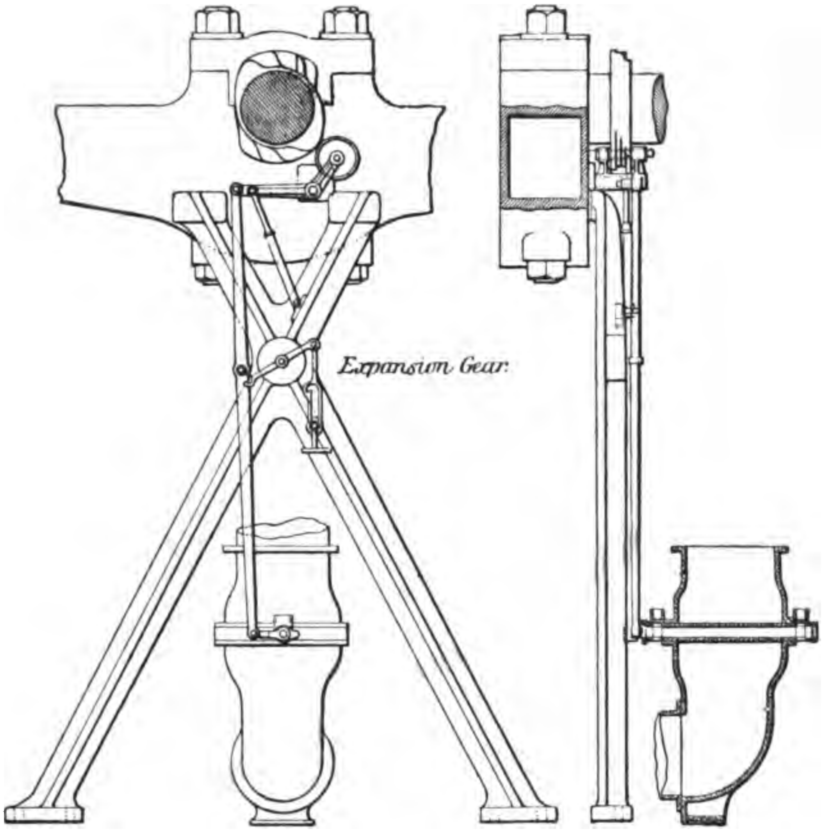

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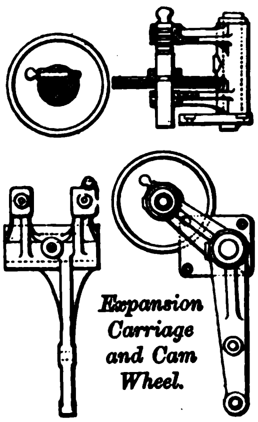

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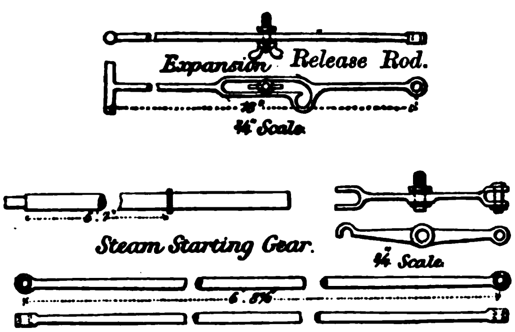
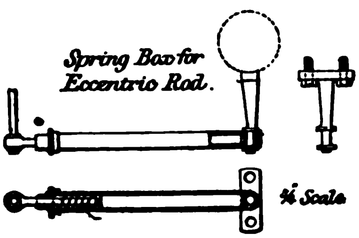


Expansion Rods and Lever.

5323



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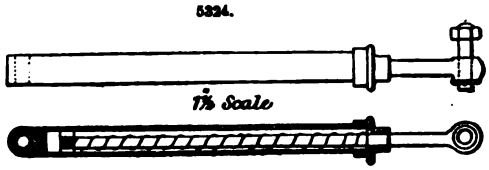
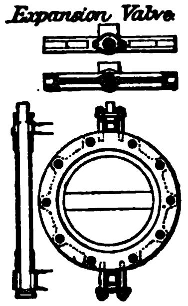


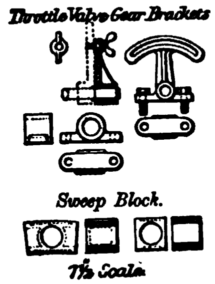
Expansion Spring Box.

5325.

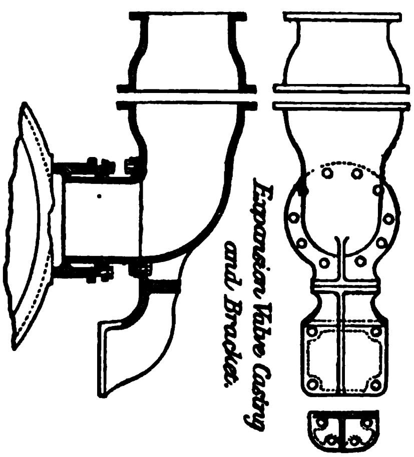


5326.

5327.



5328.



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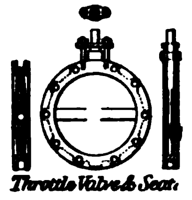


5330

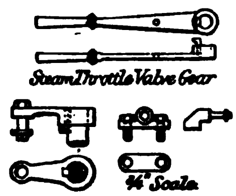


Fig. 5343 is the bilge injection-cock, and is used when open to admit water from the bilge into the condenser, whence it is pumped by the air-pump overboard, through the valve-casing, shown by Fig. 5344, which is also the main discharge-valve.

Fig. 5345 is the lower blow-out valve, or snifting valve, used for the purpose of emptying the condenser before starting the engines.

Fig. 5346, the feed or bilge pump, and casing; Fig. 5347, the plunger, and rod's connection with the same.

Fig. 5348, the bilge-water discharge-valve and casing, that is secured at the ship's side, and level above the water line with the main discharge-casing.

Fig. 5349, half of the foundation frame in sectional and complete views. The holes for the trunnion-bolts, columns, side or cross-frame bolts, and holding-down bolts are all shown, also the recesses for the feed and bilge pumps. Fig. 5350 is the cylinder trunnion-block, that is secured in the condenser and foundation frame.

Fig. 5351 represents the cross frame that supports the entablature or main top frame, and Fig. 5352 shows another support is used for the hot-water cistern.

Fig 5353, the entablature that supports the intermediate shaft and the ship ends of the paddle-shafts.

Fig. 5354, the paddle-shaft and the intermediate shaft. The piston-rod is illustrated by Fig. 5355, and the piston-rod cap, bolts, nuts, and brasses by Fig. 5356.

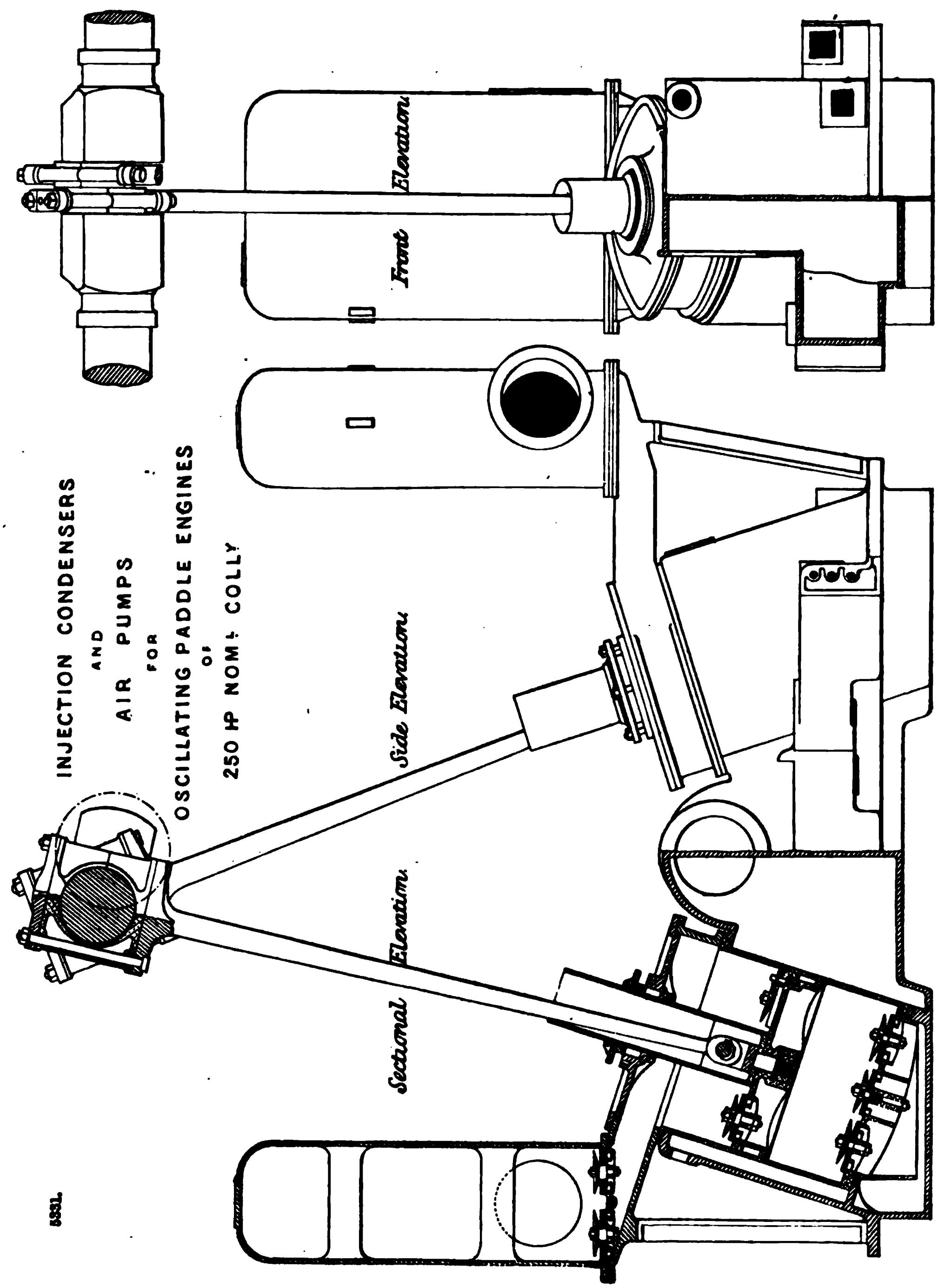
The main crank is shown by Fig. 5357, and the disengaging disc by Fig. 5358. This being arranged so that by withdrawing the two cross keys, the crank-pin band can run free on the disc, when the paddle-wheels can revolve free from the engines—this is necessary when the ship is sailing.

Fig. 5359, the plan and elevations of the starting platform; Fig. 5360, the hand-rails and stanchions; Fig. 5361, the hand-rail support brackets.

Fig. 5362, feed and bilge pipe required for these engines; and Fig. 5363, the branch steam-pipe, with stuffing-box expansion-joints; Fig. 5364, safety-valve gear.

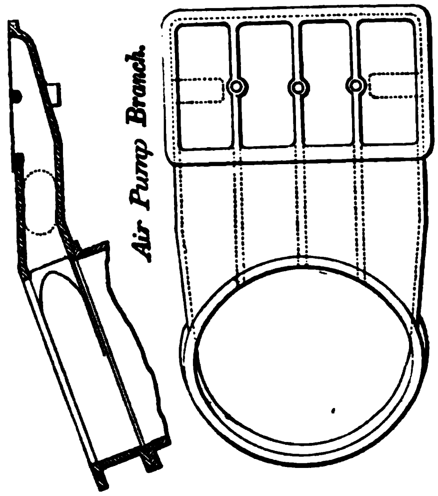
The feathering paddle-wheels of these engines are well arranged, as the Fig. 5365 illustrates by two views. The centre piece is shown by Fig. 5366. The arms, bolts, and nuts, by Fig. 5367. The radius and driving rods by Fig. 5368, and the cross stay-bolts and nuts by Fig. 5369.

See Boilers. Screw Engines.

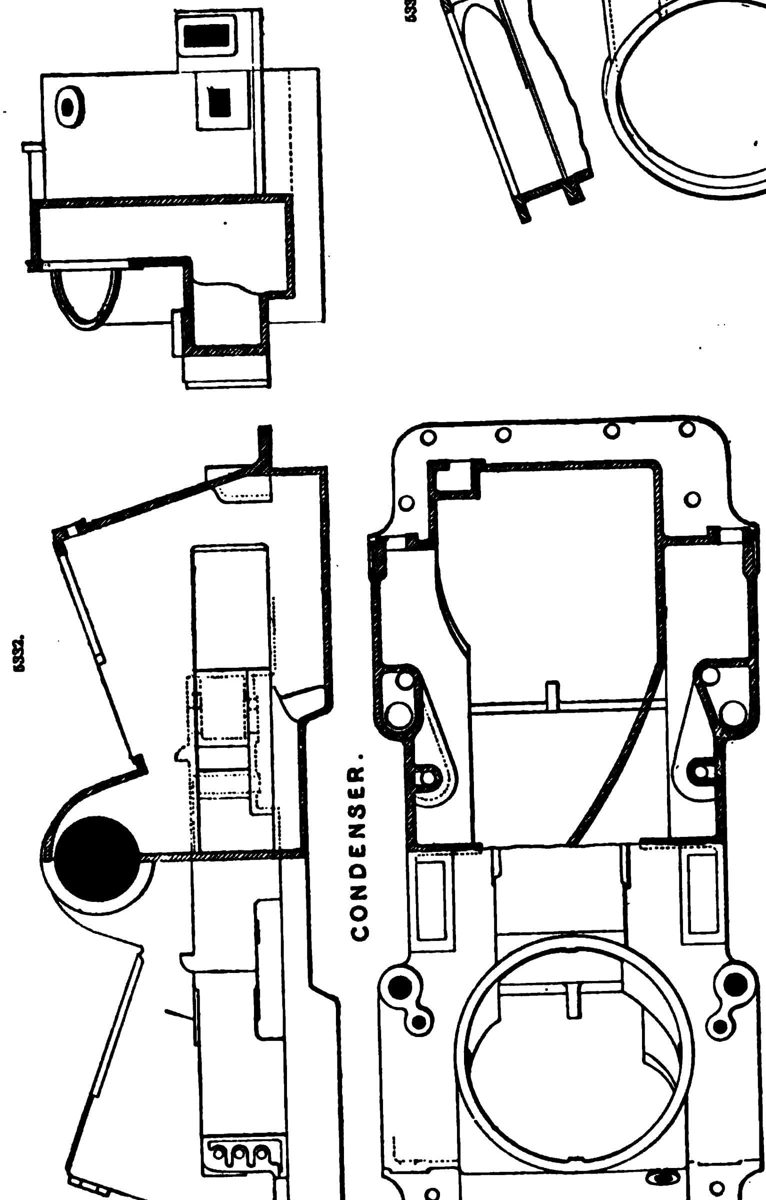

INJECTION CONDENSERS
AND
AIR PUMPS
FOR
OSCILLATING PADDLE ENGINES
OF
250 HP NOML. COLLY.
Front Elevation
Side Elevation
Sectional Elevation

5331.

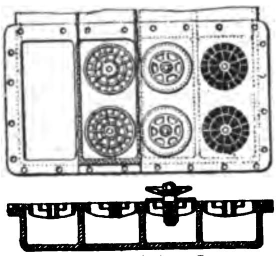
5333.



5332.

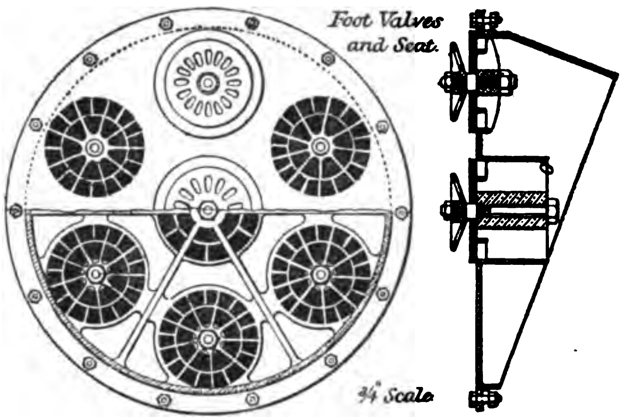


5334.



Delivery Valve Seat.

5336.



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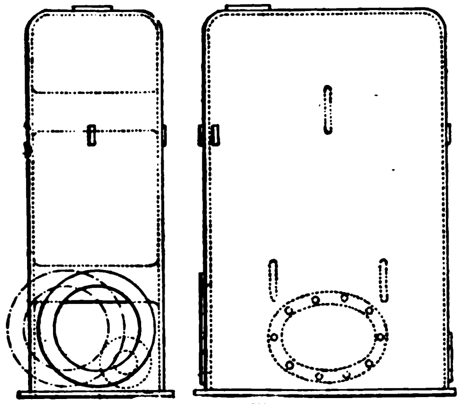
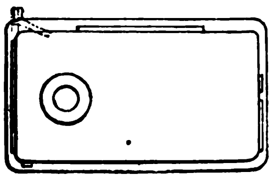


Hot Water Cistern.



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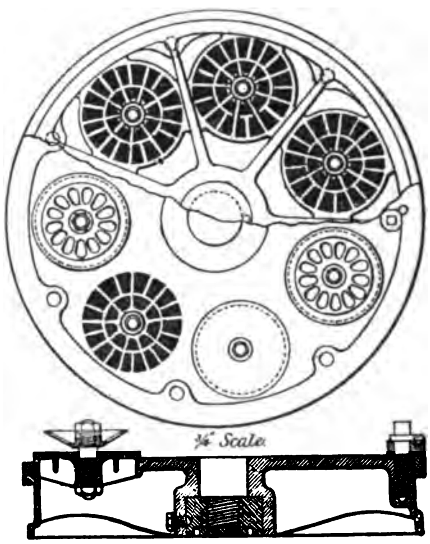

Air Pump Bucket.

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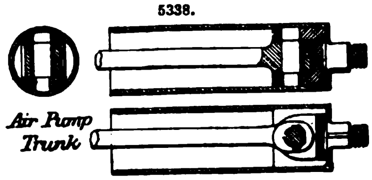

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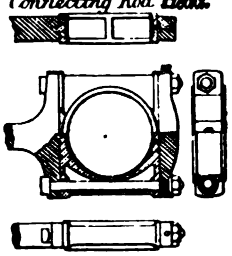
Air Pump Connecting Rod Head.



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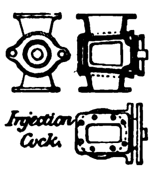

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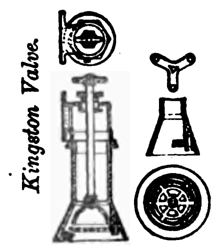

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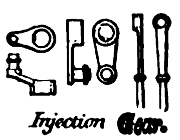

Injection Gear.

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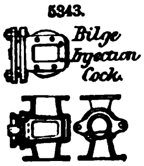

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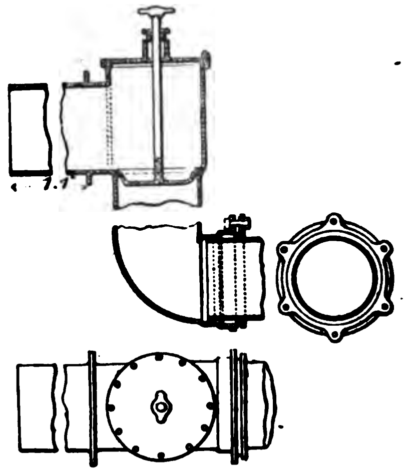

Main Discharge Valve.

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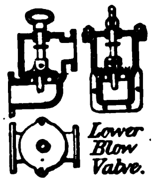

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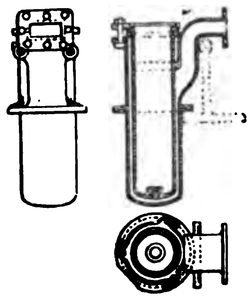

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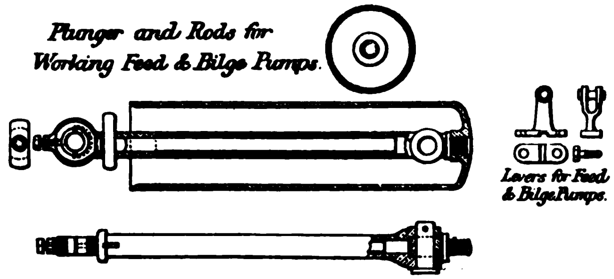

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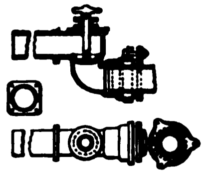

Bilge Discharge Valve.

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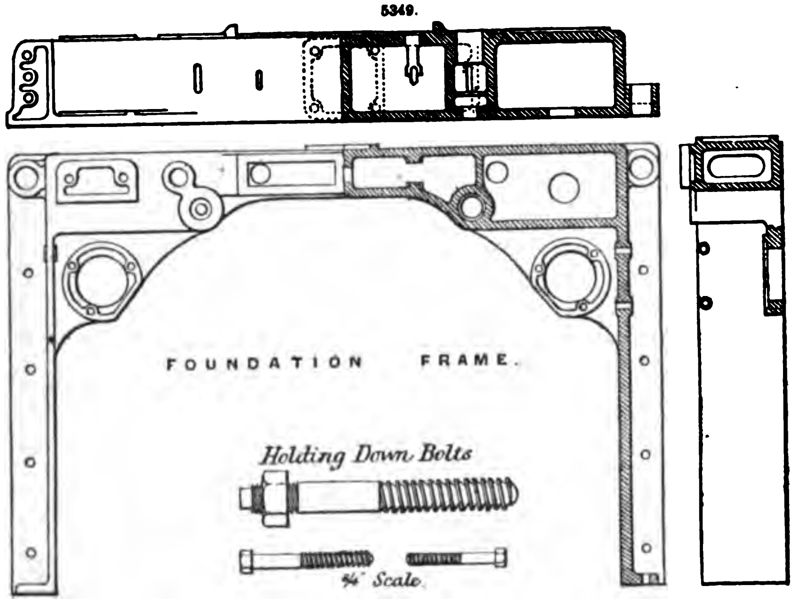

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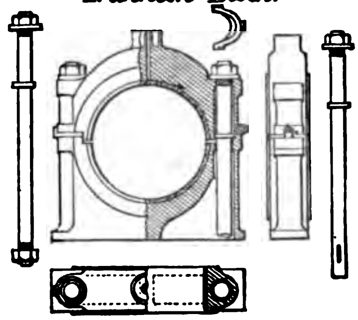
Trunnion Block.



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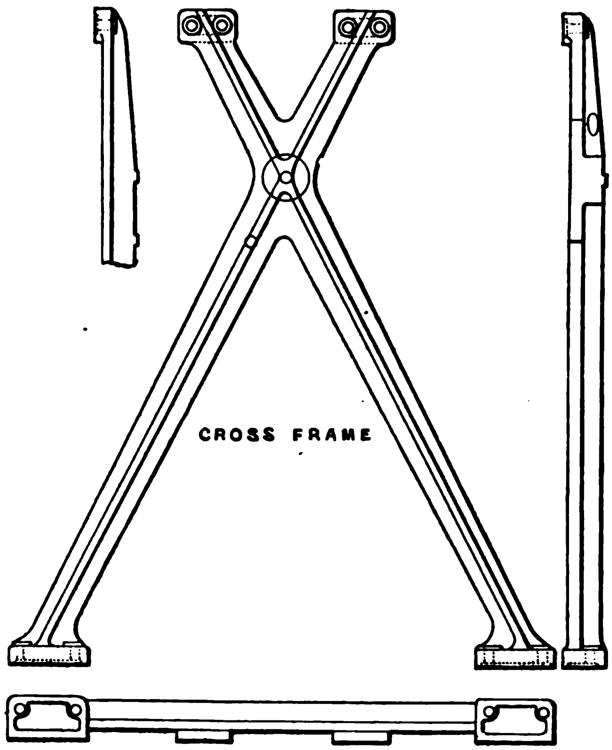
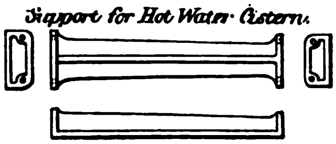


5352.

Support for Hot Water Cistern.



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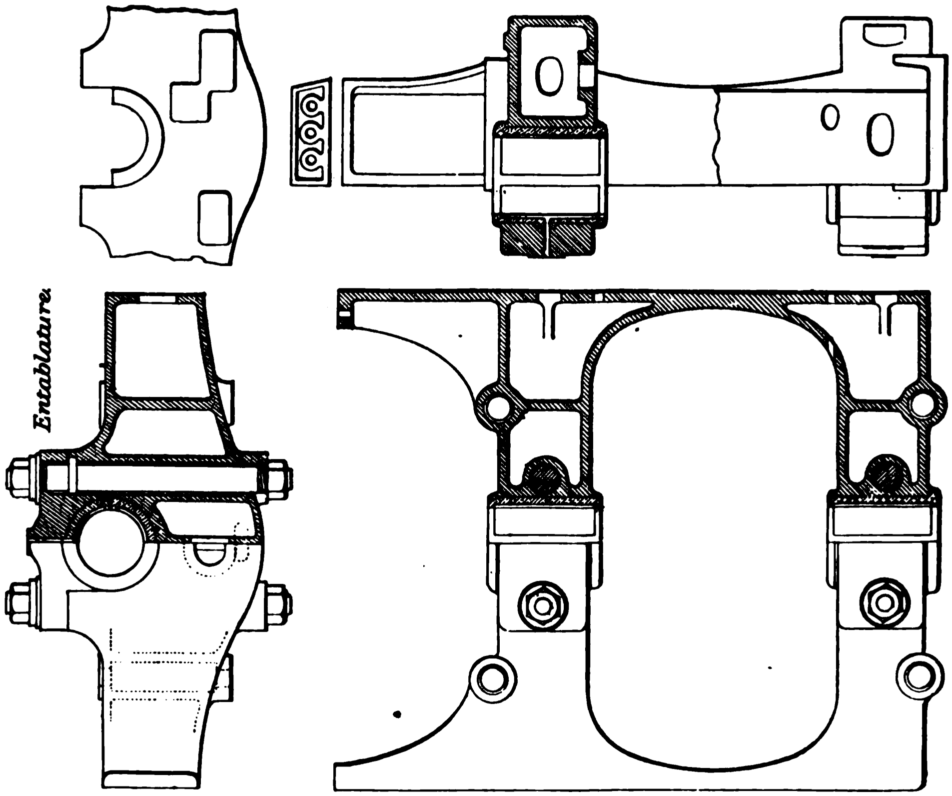
Entablature.



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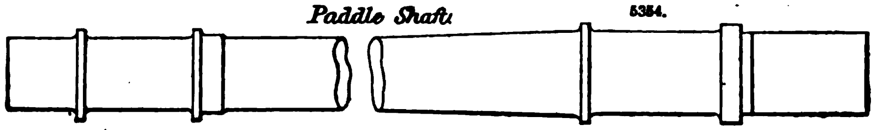

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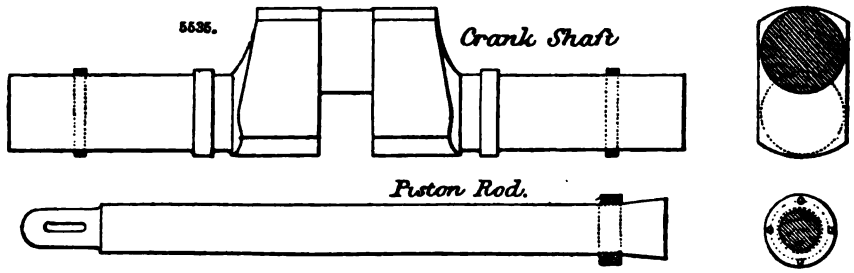

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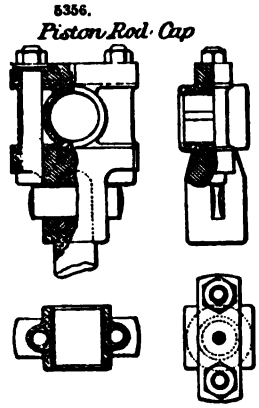

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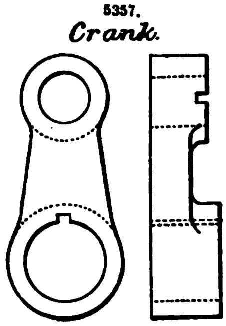

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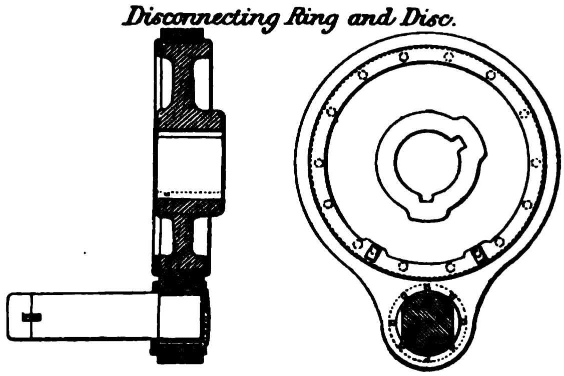

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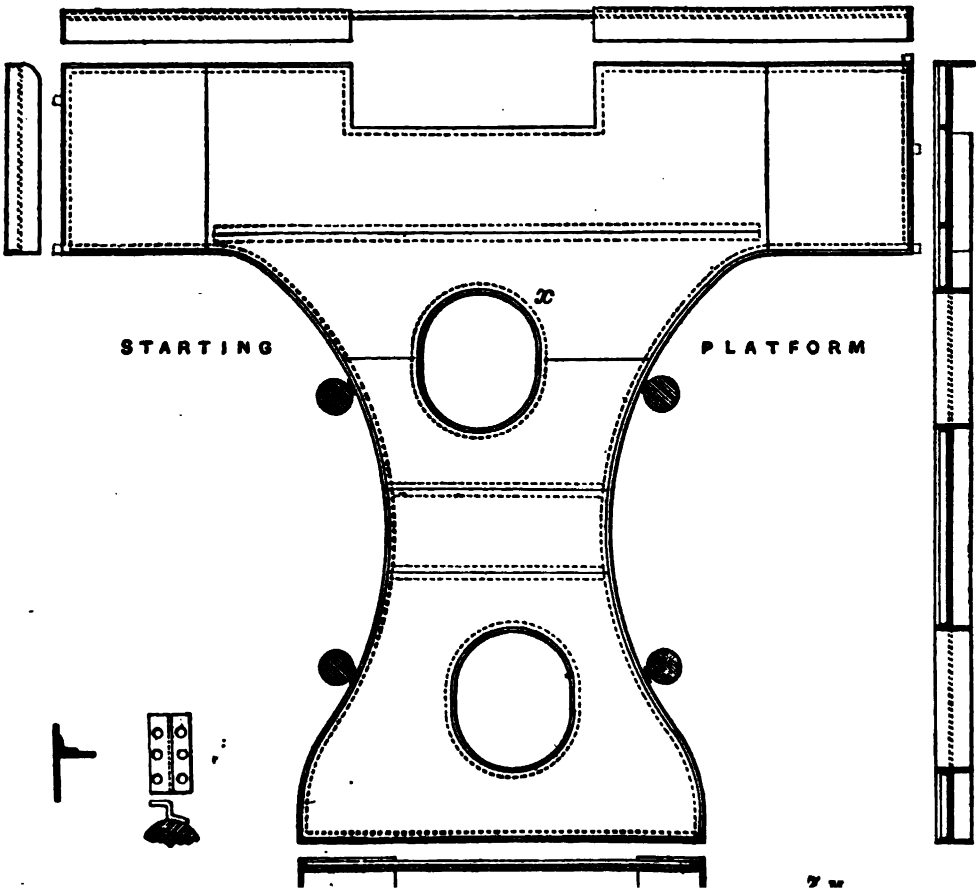

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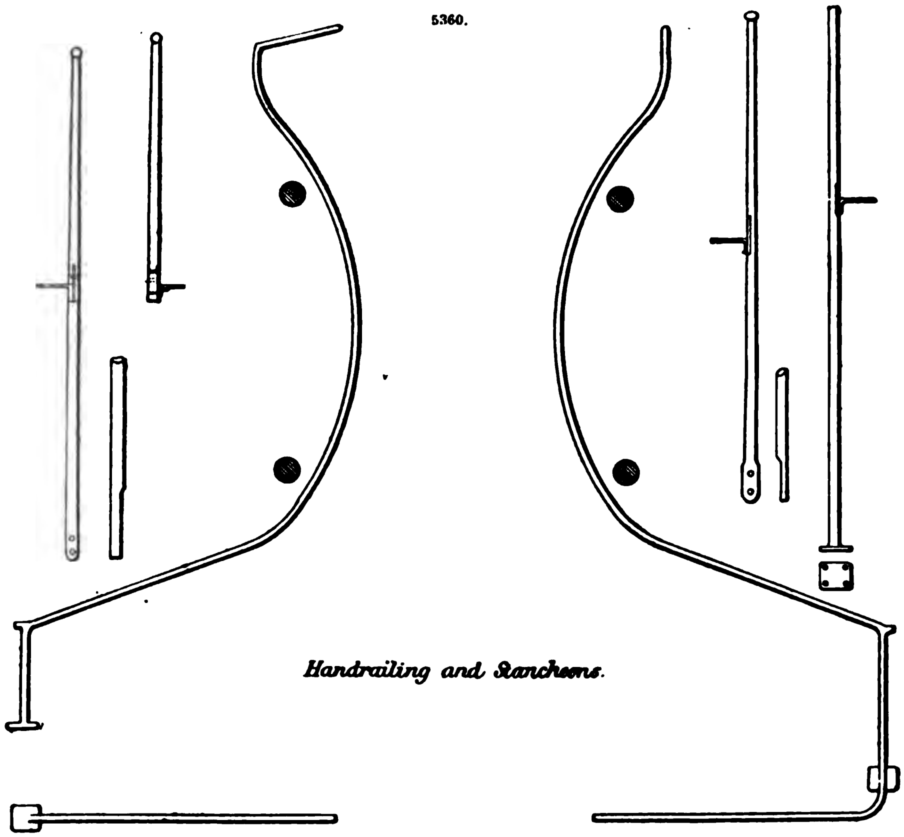
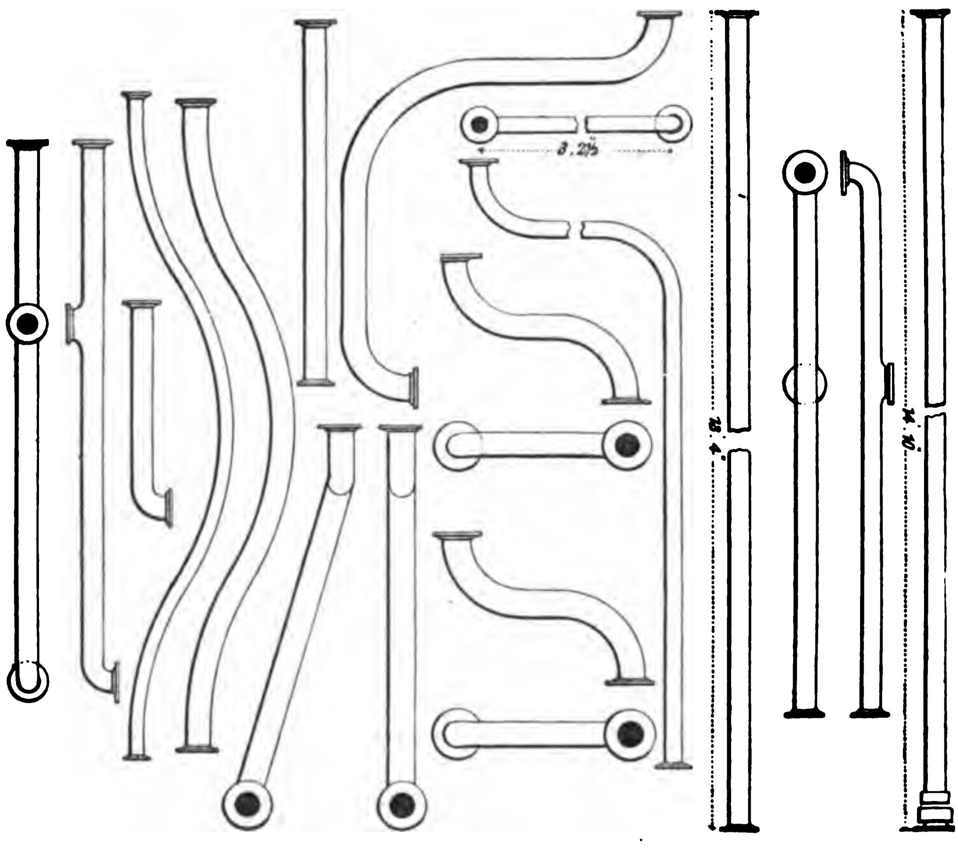
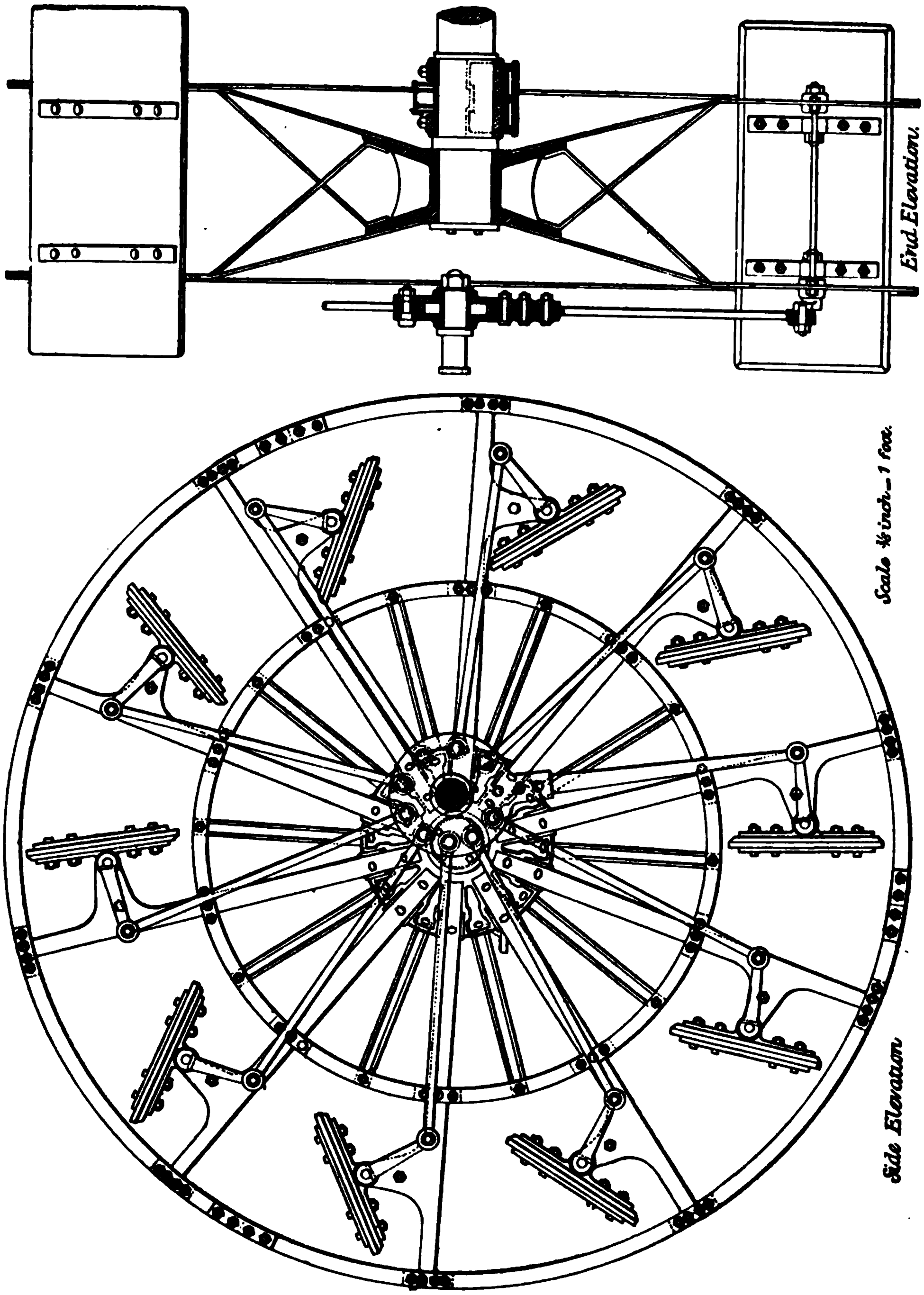


Handrailing and Stanchions.

5362.

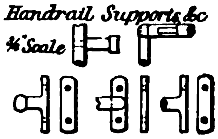
Feed and Bilge Pump Piping.





5365.
Feathering Paddle Wheel.

5361.



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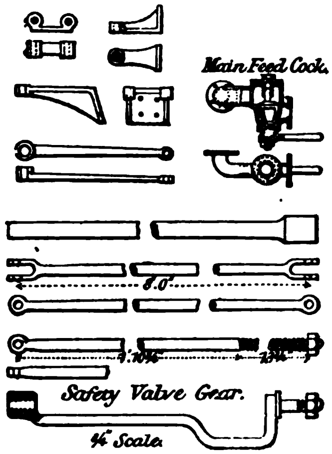

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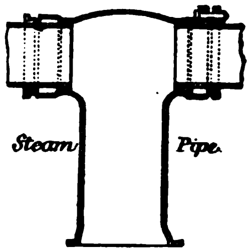
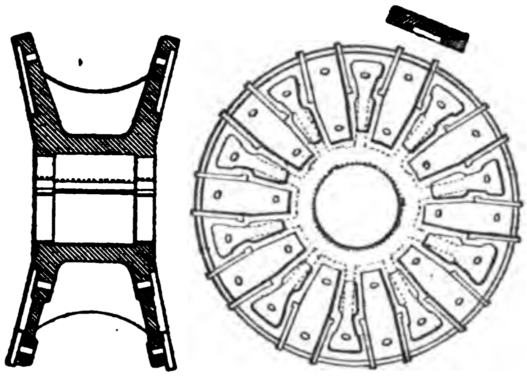


5366.
Centre Piece.



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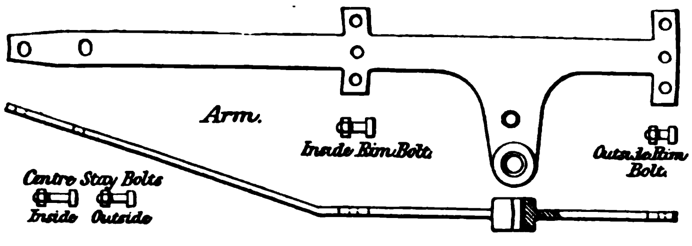

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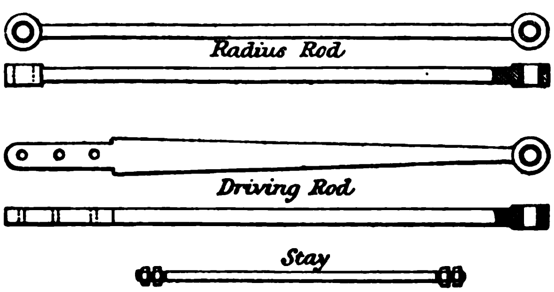

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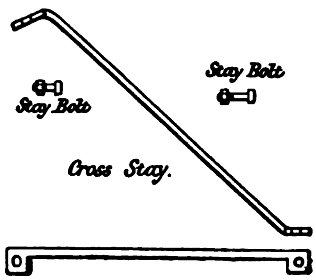


MASONRY. Fr., *Maçonnerie*; Ger., *Mauerwerk*; It., *Muramento, Fabbrica*; Span., *Albañileria*.
Masonry is the art of building in stone or brick; it is classified either from the nature of the material, as *Stone Masonry* and *Brickwork*, or from the manner in which the material is prepared, as *Cut Stone* or *Ashlar Masonry*; *Coursed*, and *Common Rubble Masonry*.

Stone Masonry.—Ashlar.—Masonry of cut stone, when carefully made, is stronger and more solid than that of any other class; but, owing to the labour required in dressing, or preparing the stone, it is also the most expensive. It is therefore chiefly restricted to those works where a certain architectural effect is to be produced by the regularity of the masses, or where great strength is indispensable.

Before explaining the means to be used to obtain the greatest strength in cut stone, it will be necessary to give a few definitions to render the subject clearer.

In a wall of masonry, the term face is usually applied to the front of the wall, and the term back to the inside; the stone which forms the front, is termed the facing; that of the back, the backing; and the interior, the filling. If the front or back of the wall has a uniform slope from the top to the bottom, this slope is termed the batter. The term course is applied to each horizontal layer of stone in the wall; if the stones of each layer are of equal height throughout, it is termed regular coursing; if the heights are unequal, the term random, or irregular coursing, is applied. The divisions between the stones, in the courses, are termed the joints; the upper and lower surfaces of the stones of each course are termed the bed. The arrangement of the different stones of each course, or of contiguous courses, is termed the bond.

The strength of a mass of cut stone masonry will depend on the quality of the stone and mortar, the size of the blocks, the accuracy of the dressing, and on the bond used.

The size of the blocks varies with the kind of stone, and the nature of the quarry. From some quarries the stone may be obtained of any required dimensions; others, owing to some peculiarity in the formation of the stone, only furnish blocks of small size. Again, the strength of some stones is so great as to admit of their being used in blocks of any size, without danger to the stability of the structure arising from their breaking; others can only be used with safety when the length, breadth, and thickness of the block bear certain relations to each other. No fixed rule can be laid down on this point; that usually followed by builders is to make, with ordinary stone, the breadth at least equal to the thickness, and seldom greater than twice this dimension, and to limit the length to within three or four times the thickness. When the breadth or the length is considerable, in comparison with the thickness, there is danger that the block may break, if any unequal settling, or unequal pressure, should take place. As to the absolute dimensions, the thickness is generally not less than 1 ft., nor greater than 2 ft.; stones of this thickness, with the relative dimensions just laid down, will weigh from 1000 to 8000 lbs., allowing, on an average, 160 lbs. to the cubic foot. With these dimensions, therefore, each block will require a very considerable power, both of machinery and men, to set it on its bed.

For the coping and top courses of a wall, the same objections do not apply to excess in length; but this excess may, on the contrary, prove favourable; because the number of top joints being thus diminished, the mass beneath the coping will be better protected, being exposed only at the joints, which cannot be made water-tight, owing to the mortar being crushed by the expansion of the blocks in warm weather, and, when they contract, being washed out by the rain.

The accuracy with which the blocks fit is dependent on the manner in which the surfaces in contact, are wrought or dressed; if this part of the work is done in a slovenly manner, the mass will not only present open joints from any inequality in the settling; but, from the courses not fitting accurately on their beds, the blocks will be liable to crack from the unequal pressure on the different points of the block.

The surfaces of one set of joints should, as an essential condition, be perpendicular to the direction of the pressure; by this arrangement, there will be no tendency in any of the blocks to slip. In a vertical wall, for example, the pressure being downward, the surfaces of one set of joints, which are the beds, must be horizontal. The surfaces of the other set must be perpendicular to these, and at the same time perpendicular to the face or to the back of the wall, according to the position of the stones in the mass. Two essential points will thus be attained; the angles of the blocks, at the top and bottom of the course, and at the face or back, will be right angles, and the block will therefore be as strong as the nature of the stone will admit. The principles here applied to a vertical wall are applicable in all cases, whatever may be the direction of the pressure and the form of the exterior surfaces, whether plane or curved.

Workmen, unless narrowly watched, seldom take the pains necessary to dress the beds and joints accurately; on the contrary, to obtain what are termed close joints, they dress the joints with accuracy a few inches only from the outward surface, and chip away the stone towards the back or tail, so that, when the block is set, it will be in contact with the adjacent stones only throughout this very small extent of bearing surface. This practice is objectionable under every point of view; for, in the first place, it gives an extent of bearing surface, which, being generally inadequate to resist the pressure thrown on it, causes the block to splinter off at the joint; and in the second place, to give the block its proper set, it has to be propped beneath by small bits of stone or wooden wedges, an operation termed pinning-up or under-pinning, and these props, causing the pressure on the block to be thrown on a few points of the lower surface, instead of being equally diffused over it, renders the stone liable to crack.

When the facing is of cut stone, and backing of rubble, the method of splaying off the joint of the block may be allowed for the purpose of forming a better bond between the rubble and ashlar; but, even in this case, the block should be dressed true on the beds, and the upright joints should also be dressed true for some distance back from the face. If there exists any cause which would give a tendency to an outward thrust from the back, then, instead of thinning off all

the blocks towards the tail, it will be preferable to leave the tails of some thicker than the parts which are dressed.

Various methods are used by builders for the bond of cut stone. The system, termed headers and stretchers, in which the vertical joints of the blocks of each course alternate with the vertical joints of the courses above and below it, or as it is termed break joints with them, is the most simple, and offers, in most cases, all requisite solidity. In this system, the blocks of each course are laid alternately with their greatest and least dimensions to the face of the wall; those which present the longest dimensions along the face are termed stretchers; the others, headers. If the header reaches from the face to the back of the wall, it is termed a through; if it only reaches part of the distance, it is termed a binder. The vertical joints of one course are either just over the middle of the blocks of the next course below, or else, at least a distance equal to half the height of the course on one side or the other of the vertical joints of that course; and the headers of one course rest as nearly as practicable on the middle of the stretchers of the course beneath. If the backing is of rubble, and the facing of cut stone, a system of throughs or binders, similar to what has just been explained, must be used.

By the arrangement here described, the facing and backing of each course are well connected; and, if any unequal settling takes place, the vertical joints cannot open, as would be the case were they in a continued line from the top to the bottom of the mass; as each block of one course confines the ends of the two blocks on which it rests in the course beneath.

In masses of cut stone exposed to violent shocks, as those of which lighthouses and sea-walls in very exposed positions are formed, the blocks require to be not only very firmly united with each other, but also with the courses above and below them. To effect this, various means have been used. The beds and joints are sometimes arranged with projections, which fit into corresponding indentations of the adjoining stones. Iron cramps are let into the top of two blocks of the same course at a vertical joint, and are firmly set with melted lead, so as to confine the two blocks together. Stones of different courses are also connected with cramps, and holes are, in some cases, drilled through several courses, and the blocks of these courses are connected by strong metal bolts fitted to the holes.

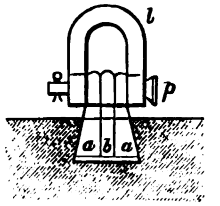
The manner of dressing stone belongs to the stonecutter's art, but the engineer should not be inattentive either to the accuracy with which the dressing is performed, or the means employed to effect it. The tools chiefly used by the workman are the chisel, axe, pick, and hammer. The usual manner of dressing a surface is to cut draughts around and across the stone with the chisel, and then to use the chisel, the axe, pick, or the hammer, to work down the intermediate portions to the same surface with the draughts. In performing this last operation, the chisel and axe should alone be used for soft stones, as the grooves on the surface of the hammer are liable to become choked by a soft material, and the stone may in consequence be materially injured by the repeated blows of the workman. In hard stones this need not be apprehended.

The scaffolding used for stonework is similar to that used for brickwork, except that it is double, that is, formed with two rows of standards so as to be totally independent of the walls for support. The construction of scaffolds with round poles lashed with cords has lately been superseded in large works by a system of scaffolding of square timbers connected by bolts and dog-irons.

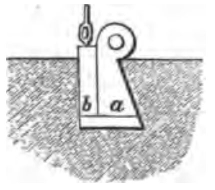
The hoisting of the materials is performed from these scaffolds by means of either a travelling crane, a movable jib-crane, or a derrick.

In hoisting blocks of stone they are attached to the tackle by means of a simple contrivance, Fig. 5370, made of iron, and called a lewis, which is shown in the annexed figure.

5370.



5371.



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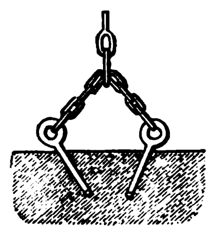


A hole tapering upwards, about 3 in. deep, having been cut in the upper surface of the stone to be raised, the two tapering side pieces *a a*, of the lewis are inserted, and placed against the sides of the hole; the centre parallel piece *b* is then inserted, and secured in its place by a pin *p* passing through all three pieces, and the ends of a loop *l* which embraces their heads. The stone may be then safely hoisted by the loop *l*, as it is impossible for the lewis to draw out of the hole. By means of the lewis in a slightly altered form, as shown in Fig. 5371, stones can be lowered and set under water without difficulty, and the lewis disengaged by means of a line attached to the parallel piece *b*, the removal of which allows the other to be drawn out of the mortise. Fig. 5372 shows a substitute for a lewis, consisting of two pins let into holes which they closely fit, sloping towards each other. When a strain is applied to the lifting chain these pieces jam in their places and support the weight of the stone.

Another way is to use large nippers or tongs, the claws of which enter a pair of holes in the side of the stone. The holes should be situated in a horizontal line, passing through or a little above the centre of gravity of the stone. Very hard stones such as granite can be lifted by a single iron plug, very slightly tapered and driven tightly with the hammer into a vertical

cylindrical hole in the top of the stone directly above its centre of gravity. At the upper end of the plug is an eye to which the chain for lifting the stone is hooked. After the stone has been laid in its place, a few sharp taps given sideways with the hammer loosen the plug.

When a block of cut stone is to be laid, the first point to be attended to is to examine the dressing, which is done by placing the block on its bed, and seeing that the joints fit close, and the face is in its proper plane. If it be found that the fit is not accurate, the inaccuracies are marked, and the requisite changes made. The bed of the course on which the block is to be laid is then thoroughly cleansed from dust, and well moistened; a bed of thin mortar is laid evenly over it, and the block, the lower surface of which is first cleansed and moistened, is laid on the mortar-bed and well settled, by striking it with a wooden mallet. When the block is laid against another of the same course, the joint between them is prepared with mortar in the same manner as the bed.

Quoins, or corner stones which should be of large size, and chosen with especial care, are at once headers and stretchers; each quoin being a header relatively to one of the two faces of the building which it connects, and a stretcher relatively to the other.

The thickness of the mortar in joints of well-executed ashlar masonry should be about ⅛ of an inch. The volume of mortar required in all is about $\frac{1}{10}$ part of the volume of the stone. Ashlar masonry is used in engineering chiefly for the piers, abutments, arches, and parapets of bridges, for hydraulic works, for facing, quoins, string-courses, and coping to inferior descriptions of masonry, and to brickwork.

A rougher kind of ashlar masonry is built with stones of the sizes and figures mentioned, but scabbled or dressed with the pick or hammer. In whatever way the faces of ashlar stones are dressed, there ought to be a chisel-draught round the edges of the face forming sharp and straight edges with the chisel-draughts of the beds and joints in order that the stone may be set accurately.

In coursed rubble masonry the building consists of a series of horizontal courses seldom exceeding 1 ft. in height, each of which is correctly levelled before another is built upon it; but the side joints are not necessarily vertical. One-fourth part at least of the face in each course should consist of bond-stones or headers; each header to be of the entire height of the course, of a breadth at least equal to the height, and of a length extending into the building to from three to four times that depth, as in ashlar. Those headers should be roughly squared with the hammer, and their beds hammer-dressed to approximate planes; and care should be taken not to place the headers of successive courses above each other, as that arrangement would cause a deficiency of bond in the intermediate parts of the course. Between the headers each course is to be built of smaller stones, of which there may be one, two, or more in the depth of the course. These are sometimes roughly squared, so as to have vertical side joints; sometimes the stones are taken as they come, so that the side joints are irregular; but no side joint should form an angle with a bed joint sharper than 60°. Care should be taken not only that each stone shall rest on its natural bed, but that the sides parallel to that natural bed shall be the largest, so that the stones may lie flat, and not be set on edge or on end. However small and irregular the stones may be, care should be taken to make the courses break joint. Hollows between the larger stones should be carefully filled with smaller stones completely imbedded in mortar.

Coursed rubble masonry requires great care in the inspection of its progress to see that the preceding rules are observed; and especially that the interior of the wall contains neither empty hollows, nor spaces filled wholly with mortar or with rubbish where pieces of stones ought to be inserted, and that each stone is laid flat and on its natural bed. Care must be taken that the headers or bond-stones are really what they profess to be, and not thin stones set on edge at the face of the wall.

A cubic yard of rubble masonry requires, in order to allow for waste, about 1¼ cub. yd. of stones and ⅓ cub. yd. of mortar.

The resistance of good coursed rubble masonry to crushing is about four-tenths of that of single blocks of the stone that it is built with.

Coursed rubble is used for retaining walls and wing-walls that require less strength than those built of ashlar, for the backing of pieces of masonry that are faced with ashlar for fence-walls, and for various other purposes.

Rubble is often built in random courses, that is to say, each course rests on a plane bed, but is not necessarily of the same depth or at the same level throughout, so that the beds occasionally rise or fall by steps.

Common rubble masonry differs from coursed rubble in not being built in courses; but in other respects the same rules are to be observed.

The resistance of common rubble to crushing is not much greater than that of the mortar which it contains; it is therefore not to be used when strength is required unless built with strong hydraulic mortar. Its chief use in engineering is for fence walls.

Ashlar backed with Rubble.—In this sort of masonry the stones of the ashlar face should have their beds and joints accurately squared and dressed with the hammer or the point, as the case may be, for a breadth of from once to twice the depth of the course inwards from the face; but the backs of these stones may be rough. The proportion and length of the headers should be the same as in ashlar, and the tails of those headers or parts which extend into the rubble backing may be left rough at the back and sides; but their upper and lower beds should be hammer-dressed to the general planes of the beds of the courses. These tails may taper slightly in breadth, but should not taper in depth.

The rubble backing should be carried up at the same time with the face-work, and in courses of the same depth, the bed of each course being carefully formed to the same plane with that of the ashlar facing.

In estimating the labour or cost of building such masonry as is here described, the area of the face multiplied by the distance inwards to which the dressing of the joints is carried, may be taken as ashlar, and the remainder as rubble.

These combinations of masonry are the most generally useful in engineering works; and they are especially suitable in a mechanical point of view where the pressure is concentrated towards the face of the building, as in retaining walls. For the abutment of bridges they are not mechanically suitable, because the pressure is concentrated towards the back; but if in any bridge coursed rubble is strong enough to resist the pressure at the back of the abutments, it may be used for that purpose, and faced with ashlar, for the sake of appearance, and of protection from the weather.

Coursed rubble masonry is often used in combination with ashlar quoins.

The following is the specification for the stonework used on a branch railway, and will be found a good guide for similar work elsewhere;—

Ashlar will be of two kinds—1st, smooth-faced or tooled ashlar; and 2nd, fair broached and rock-faced ashlar, with or without a chisel-draught round the edges; the rock-facing, where used, not to project more than 2 in. beyond the face of the chisel-draught or arris.

It is proposed to use but a limited proportion of this class of work, which will be principally confined to imposts, bed-plates for girders, springers, string-courses and copings, and occasionally in quoins and walling, and large arches, but power is reserved to use it wherever it may be deemed necessary.

Thickness of Ashlar Courses, and General Arrangement.—No course of ashlar to be less than 8 in. thick. One-third of the entire length of each course to be headers. No stone to be less than 2 ft. long, and when the thickness of the course does not exceed 10 in., the stones must not be less than 15 in. on the bed. Where the thickness of the ashlar courses exceeds 10 in., the breadth of the beds will not be less than a third more than the thickness of the course.

No header to be of less length than 18 in. in excess of the breadth of the course of ashlar to which it belongs. In walls up to 3 ft. thick, all headers to be through stones. The beds and joints of all ashlar stones to be dressed perfectly true, square, and full. No hollow beds will be allowed.

The vertical joints in all cases to be dressed true and square for at least two-thirds of the breadths of the beds in from the face of the work.

No joint to exceed $\frac{1}{8}$ of an inch in thickness.

The courses to be arranged with as much uniformity as possible, and laid perfectly horizontal, the lighter courses being kept towards the top of the structure.

The vertical joints of each course not to have less than 6 in. lap over the joints of the course next below. The work to be thoroughly well grouted after every course.

Ashlar in Copings.—The coping-stone will, as a rule, be dowelled, but the engineer may dispense with this system in such cases as he may deem expedient.

No stones in the ashlar copings to be less than 2 ft. 6 in. long, and the exposed surfaces to be dressed to a smooth face.

Large Rough Stone Blocks.—It may be necessary to use one or more courses of rough stone blocks in the foundations of bridges; such blocks to be only quarry scabbled, and none less than 8 in. thick, or less than 8 sq. ft. in area. These blocks to be measured half as ashlar, half as rubble; they are to be laid in mortar, and great care is to be taken that they rest evenly on their beds.

Coursed Rubble Facing.—This class of work will be extensively used. In bridges up to 20 ft. span no course to be less than 3 in. in thickness. When the span exceeds 20 ft., the minimum thickness of a course to be 4 in.

In structures other than bridges the minimum thickness may be 3 or 4 in., at the discretion of the engineer. No stone to be less than 9 in. long upon the face, or less than 8 in. on the bed.

In courses of 6 in. and upwards, no stone to have a bed less than one-third more than the thickness of the course in which it occurs.

One-fifth of the whole length of each course to be headers.

No header to be less than 2 ft. long. All rubble quoins to be formed of header-stones laid alternately along each face.

The vertical joints of each course not to have less than 3 in. lap over the joints of the course next below.

The joints in all cases to be dressed as far back from the face of the work as the thickness of the course in which they occur.

The beds are to be dressed level, so as to rest evenly on the mortar without any hollows or projections.

The faces of the stones to be left rough, but no part to project more than 1 in. beyond the face arrises, which are to be in all cases chipped off square.

The joints to be dressed square, true, and full, and no mortar joint to exceed $\frac{1}{2}$ an inch in thickness; and the average of the joints to be under $\frac{1}{4}$ an inch.

Face-work of this nature will be measured one-fifth more than the breadth of the courses, to compensate for the headers, on the same principle as is noted in the specification of ashlar.

Arrangement of Courses.—All the courses are to be kept perfectly horizontal, but uniformity in the thickness of each course throughout its entire length will not be insisted on. Every care must be taken to ensure proper skill in the arrangement of the work generally, and specially where changes in thickness of the courses occur; and where ashlar quoins or courses are used with the rubble, the latter must be brought up to the ashlar with a perfectly level bed.

The thicker courses are to be used in the lower portions of the work, and are also to be selected for the building of the piers and abutments, or other important walls.

At every 2 ft. in height it will be necessary to bring the masonry to a perfectly horizontal bed throughout the entire length of each particular wall, and to thoroughly well grout the whole.

In all stonework the stones are to be laid on their natural beds.

In all cases where battering walls are required, the beds of the stones are to be at right angles to the batter.

The face joints in all stonework are to be raked clean and neatly pointed, and the whole work carried on and completed to the entire satisfaction of the engineer.

Rubble Backing is to be of the best materials and workmanship, built of good sound stones. No stone to be of smaller size than one quarter of a cubic foot.

The stones of the rubble backing to be carefully set and well bonded with themselves and with the face-work. The whole to be laid flush in mortar so as to leave no spaces.

The interstices between the stones to be filled in with spauls or quarry chips. The larger stones to be roughly picked when necessary, so that they may rest evenly on their beds without hollows.

The rubble backing to be brought up flush with the face-work for every 2 ft. in height of the walls, and well grouted; and in no case will the building of the backing be allowed to proceed in advance of the face-work.

The joints in the back of all rubble walling to be raked and completely rough pointed.

Stone Pitching.—To be of the same class of stone as the rubble face-work; the face to be kept roughly dressed, and the stone to be as nearly as possible of a uniform depth. This pitching will be set on a layer of concrete of rubble, not less than 6 in. thick, as described for backing, and the whole must be thoroughly well grouted.

See BOND. BRIDGES. CONSTRUCTION. HARBOUR. LIGHTS, BUOYS, and BEACONS.

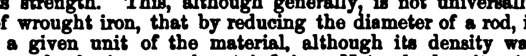
Books on Masonry;—Aviler (A.), 'Dictionnaire d'Architecture,' 4to, 1755. Nicholson (P.), 'Masonry,' royal 8vo, 1826. Adhemar, 'Traité de la coupe des Pierres,' 8vo and 4to, Paris, 1845. Nicholson (P.), 'Guide to Railway Masonry,' 8vo, 1846. Robson (R.), 'Mason's Practical Guide,' 4to, 1865. Dupuit (J.), 'Traité de l'Equilibre des Voûtes et de la Construction des Ponts en Maçonnerie,' 4to, Paris, 1870. Burn (R. S.), 'New Guide to Masonry,' 4to, 1871. Langley (Batty), 'Ancient Masonry,' 2 vols. folio. See also Belidor, Gauthey, Perronet, Rondelet, and Sganzin.

MATERIALS OF CONSTRUCTION, STRENGTH OF. FR., *Résistance des Matériaux*; GER., *Festigkeit*; ITAL., *Resistènza dei Materiàli*; SPAN., *Resistencia de Materiales*.

The strength of any material is the resistance it opposes to fracture, in whatever manner that fracture may be brought about. According to the nature of the force, or strain, tending to produce fracture, so is the strength of the material denominated. Thus the tensile strength of wrought iron, or its resistance to a strain of a tensile character, is greater than that of cast iron. In other words, it will require a greater tensile force, or strain, to fracture a given unit of the former than of the latter material. Again, we have the terms compressive strength, transverse strength, torsional strength, each expressing the resistance of the material to a strain of that particular character. The strength of materials is due to the force of cohesion existing between their component particles. Cohesion may be briefly described as that force which tends to prevent the separation of the particles of a body, when that body is acted upon by any external force. It might be supposed from this that the closer the particles of a body are together, or the denser it is, the greater is its strength. This, although generally, is not universally true. It has been found, in the case of wrought iron, that by reducing the diameter of a rod, it has become stronger than before, for a given unit of the material, although its density was absolutely diminished. The modifications of cohesion are almost infinite. Not only does it exist naturally, in different degrees, in different bodies, but it can be increased, decreased, or totally destroyed by artificial means. Of the real nature of cohesion we know nothing, any more than we do of the real nature of the imponderable elements. We know them only by their effects. It is reasonable to imagine that when the particles of a body are at rest, that is, when the body is not acted upon by any external force, those particles are maintained at a constant uniform distance apart, by a series of mutual corpuscular attractions and repulsions, which balance each other. Directly any external force is brought to bear upon the body, this state of normal cohesive equilibrium is disturbed, and the particles resist the disturbing action with a force proportional to that applied to them. The great problem in connection with the subject of cohesion, which has hitherto remained unsolved, is to discover the conditions which determine this state of equilibrium. If we could once discover the law of the arrangement of the particles among themselves, we should not only be enabled to ascertain to what particular arrangement a particular kind of resistance in a body is due, but we should be able to predict what would be the result of assigning any given relative position to the particles of a body. In the idea we entertain respecting the nature of the force of cohesion, it is necessary to assume the existence of a repulsive as well as of an attractive action. If the latter only existed, the particles of a body would be drawn nearer and nearer to one another, until they came into contact, and there would be no such a quality as porosity. But we know, as a fact, that the densest bodies are, to a certain extent, porous. On the other hand, if the former force were the only one brought into play, the particles of the body would be eventually dissipated into space. The normal condition of equilibrium, among the particles of a body, is therefore that in which the attractive and repulsive forces balance each other, being equal and opposite to one another. This condition, moreover, presupposes that a certain interval of space exists between the particles of all bodies.

A further consideration of this question will introduce us to another property, also possessed in a greater or less degree by all bodies, which is termed elasticity. This property is a very important one, and intimately connected with the strength of materials. Let A and B in Fig. 5373 be two particles of a body in a state of normal equilibrium, that is, separated by the distance which allows the attractive and repulsive forces to balance one another. If the former equal x and

5373.

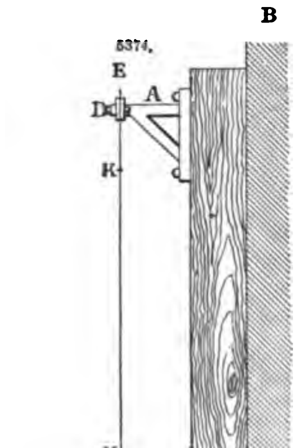


the latter y, we have the condition of equilibrium expressed by the equation $x = y$. Let an external force equal to P, now act upon the particle B, and push it towards A. As the attractive force between the particles A and B is constant, the latter force now pushing B towards A, is equal to

$x + P$, and also $x + P > y$. The particle B will continue to move towards A until the repulsive action becomes equal to the attractive action + the external force. Let C be the new position of the particle, and y_1 the new repulsive force, and the equation of equilibrium will be $x + P = y_1$. If the particle B be pulled away from A to the position D we shall have, by analogous reasoning, $y + P = x_1$. In the one case $P = y_1 - y$, and in the other $P = x_1 - x$. If B move towards A, without the application of an external force, then $x > y$. If it move from A, then $x < y$. After the particle B has come to rest at the point C or D, let the external force P be removed. What will take place? The two forces of attraction and repulsion will endeavour to resume their former equality, and to restore the particle B to its original position at B, and we shall again have $x = y$. This tendency constitutes the elasticity, or the elastic reaction, of a body. A body is said to be perfectly elastic when it resumes the exact form it had, previous to the application of the external force; that is, when the particle B, in the figure, returns exactly to the point B, after having moved either towards or from A. This coincidence depends upon certain circumstances connected with the laws of elasticity, which will be explained as we proceed. Upon them depend the deflection of beams and girders, and the safe loads which the engineer and the architect can place upon them. The theory of the propagation of light, heat, sound, and of many other physical phenomena, is dependent upon the laws governing the elastic medium, through which they are supposed to travel.

The different kinds of elasticity are known by names corresponding to the different kinds of strains to which bodies can be subjected. Thus, there is the elasticity of tension, of compression, of flexure, and of torsion. The value of these different elastic reactions can be ascertained by accurate measurement, and the laws which govern them, deduced. The same law applies equally to the elasticity of tension and that of compression, experiment having proved that it requires practically the same force to compress a rod by a given amount as it does to stretch it. To refer to Fig. 5373, if the points C and D be situated at equal distances from B, then will $x_1 = y_1$. The laws which govern the elasticity of tension can be mathematically deduced from the following experiment described by Jamin. In Fig. 5374, let A be a cast-iron bracket, solidly fixed to the wall B through the vertical wall-plate C. The bracket is terminated at one end, by a face of tempered steel, the surface of which is roughened similar to that of a file. Against this is placed another steel plate, also roughened, and the two can be tightened up by the bolts D, like the jaws of a vice. Between these two steel jaws is fastened one end of the rod E, the other end of which is held in a similar vice F. To the under part of the lower vice is attached a box G, containing a number of weights, arranged in horizontal layers, and capable of being moved with facility. To prevent the sudden shock that might arise from placing the weights incautiously in the box, and the possible fracture of the rod in consequence, the bottom of the box is furnished with three adjusting screws, H, H, H, similar to those used in theodolites and transit instruments of an old pattern. At the commencement of every experiment, these screws are lowered until they rest upon the ground, so that the weight of the box is also borne by the ground. The weights are then introduced, and the screws gently turned until they are raised from the ground, and the weight of the box and the contents brought to bear upon the rod. One precaution must be observed here. The rods, when they are of small diameter, do not hang in a straight, but in a curved line, and consequently the first result of the application of the weights is to straighten them, and also, apparently, to lengthen them. As this apparent elongation must not be confounded with that which is real and necessary to the object of the experiment, a small initial weight must be applied, in the first instance, sufficient to straighten the rod, and the measurement, obtained from the action only of the weights, subsequently added. Since the elongations of the rod are always very small, a cathetometer is employed to measure them, an instrument which we shall proceed to describe.

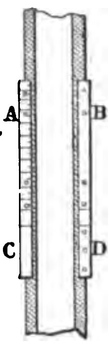
5374.



Cathetometer.—The cathetometer was invented by Dulong and Petit, improved by Pouillet, who bestowed its name upon it, and extensively employed by the celebrated chemist, Regnault. It is shown in Fig. 5375, and consists, in its simplest form, of a vertical graduated rod, upon which slides a horizontal telescope. With the telescope, the observer sights the two objects under examination, and the distance on the graduated rod, moved over by the telescope, is the measure of the difference of height between the two objects. The cathetometer rests upon a cast-metal tripod A, which is furnished with adjusting screws B, and levels C. From the centre of the tripod rises the solid wrought-iron shaft, which is about 4 ft. 3 in. in height, and before being fixed is carefully turned in a lathe, and brought to a conically-shaped bearing at the lower extremity. The axis of the instrument is that of the bearing, and it passes through the summit. The rod or shaft is covered by a hollow brass tube D, which is also turned in a lathe, so as to fit over the conical bearing of the rod. At the top it is furnished with a screw E. The tube can turn all around the axis of the rod, and can be fixed, at any time of the revolution, by a clamping screw. The tube carries on the outside two graduated rules or scales F and G, which are parallel to the vertical axis

of the instrument, and the edges of which are bevelled. One of them is divided throughout its whole length into millimètres. Upon this double rule slides the part of the apparatus carrying the telescope and its adjuncts. It is in two pieces, which clasp the rule as shown at H K in Fig. 5375, and at A B, C D, in Fig. 5376. They move with a slight friction upon the edges of the rules, and as the surfaces are lubricated, the movement is smooth and gentle. They can be clamped at any moment by the clamping screw C, and the distance they have travelled, read off by the vernier A, which reads to the $\frac{1}{50}$ of a millimètre. The two pieces H and K are distinct in themselves, but united by the tangent-screw H K, Fig. 5375, which draws them together or separates them. When they are clamped by the screw C, Fig. 5376, the turning of the tangent-screw will raise or lower the upper part K, which carries the telescope, so that the sight can be adjusted with the greatest precision. The telescope L M is provided with a spirit-level, by which its horizontal position is ensured. The level rests upon two Y^s, in the ordinary manner. The cross-piece carrying the Y^s is brought into a horizontal position by the screw N, which inclines it in one direction or the other. The instrument is set up and adjusted for observation as follows;—In the interior of the telescope, a pair of spider threads are fixed at right angles to one another, in such a manner that the threads and the image of the object observed, are seen at one and the same time. The threads can be brought to bear upon the smallest object. In every telescope there is a certain well-defined line, termed the optical axis, which passes through the intersection of the threads, or cross wires, as they are technically called, and the centre of the object-glass. When the image of any point in an object coincides with the intersection of the cross wires, the object itself is situated on the prolongation of the optical axis. On the outside of the telescope are fixed two collars A B, Fig. 5377, which are made in one piece, and afterwards cut into two. They have a common axis, which is the geometrical axis of the telescope. If the telescope is turned round in the collars, the geometrical axis will not be displaced, and the first step towards adjusting the instrument is to make the geometrical and optical axes coincide, an operation which is effected by means of the cross wires. This coincidence is known to be accomplished when the telescope can be turned round in the collars, without the intersection of the cross wires shifting, in the slightest degree, from the point upon which they are fixed. When the two axes are made to coincide, they will maintain that position permanently, provided the instrument is not subjected to any rough usage. Before observing with the cathetometer, there are three other adjustments to be made. The first is to place the telescope parallel to the spirit-level, the second is to place it perpendicular to the edges of the scales, along which it slides, and the third to ensure the verticality of the axis of rotation. In Fig. 5378, let A B be the axis of the telescope, C D the spirit-level, and E the position of the bubble. If A B and C D are parallel, and the telescope is turned end for end, A B and C D will become A_1 B_1 and C_1 D_1, and the position of the bubble will remain unaltered. But if the position of the level in the first instance is F G, it will, after turning the instrument end for end, be F_1 G_1, and the bubble will change its place, since it runs always towards the highest end of the tube. By the screws attached to the level it can be adjusted, until the bubble retains its horizontality in all positions of the instrument. In

5376.



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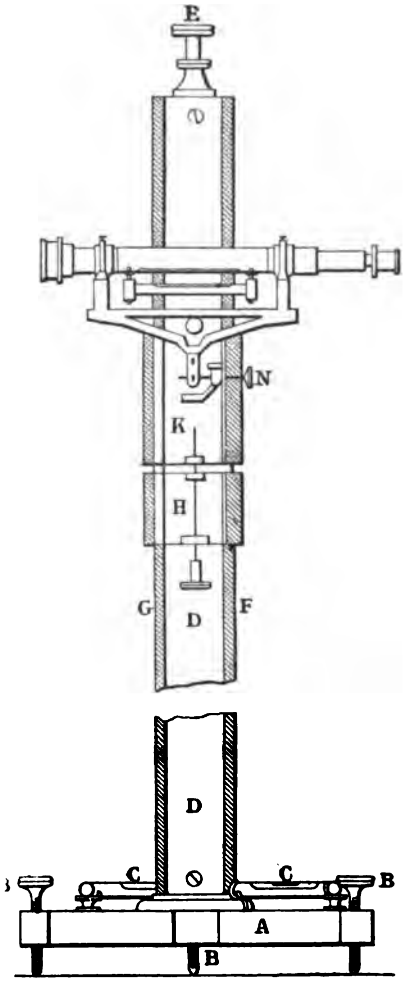

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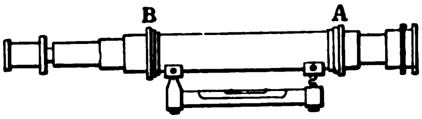
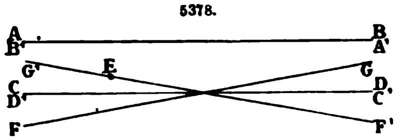
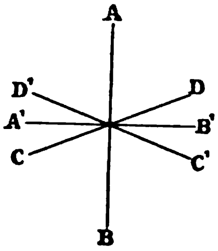


5378.

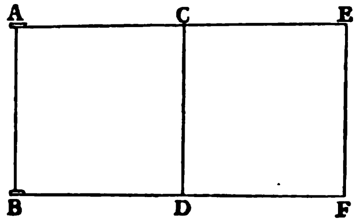


order to place the telescope perpendicular to the axis A B, in Fig. 5379, it must be turned through a half circle round the fixed shaft, and if the bubble does not change its position, the instrument is in proper order. But if the telescope is not perpendicular to the axis A B, that is in the line A_1 B_1 before its semi-revolution, let it be represented by the line C D, it will afterwards take the direction of C_1 D_1, and the bubble will change its place. By moving the screw N, acting upon the cross-piece in Fig. 5375, the bubble can be made to remain horizontal. To make the axis of the instrument vertical, the telescope is moved until it is brought into the direction parallel to the line, joining two of the adjusting screws in the tripod, and one of these screws turned until the bubble is at the centre of its run. The instrument is then rotated through an arc of 90°, and the third screw turned, until the bubble arrives at the same position as before. The adjustments are then complete, and the instrument fit for recording observations, provided the following precautions be employed. On each occasion that the telescope is moved vertically along the scales, the spirit-level will undergo slight oscillations. In Fig. 5380, let A and B represent the two positions of the level, which are not parallel to one another, and the differences of the height C D and E F of the points sighted are not equal to the distance A B travelled over by the telescope, and the error increases with the distance of the points observed. It is necessary therefore to slightly adjust the cross-piece at each observation, to bring the bubble to the centre of its run. In consequence of this necessity for continually moving the cross-piece, the tripod of the cathetometer is provided with two fixed spirit-levels, which are adjusted once for all, and serve to place the axis in a vertical position.

5379.



5380.



Let us now return to our experiment on the elasticity of tension in Fig. 5374. The cathetometer is set up in front of the arrangement shown in the figure, and accurately adjusted. A couple of fine marks K K are then made with a file on the rod. Care is taken to always sight the same edges of the marks, which are considerably magnified by the powerful lenses of the telescope attached to the cathetometer, and their distance, measured by the instrument, is given by the length of the rule at each phase of the experiment. This measurement is independent of any accidental vibrations and deflections that the arrangement may be subjected to. It can now be ascertained if the elongation is proportional to the length of the rod. If a number of marks are made on the rod at equal distances, and their respective distances from a given datum mark ascertained to be, under the action of an initial load, 1, 2, 3, 4, they become $1 + a$, $2 + 2\,a$, $3 + 3\,a$, and so on, when the tension is increased, thus proving that the elongations are in the direct ratio of the lengths of the rods. It can be also proved that they are proportional to the weights applied, and inversely proportional to the sectional area of the rods. As all bodies will not stretch to the same extent under the same weight, each body will have a coefficient of extension, or a constant of its own. If E = the elongation of a rod due to a weight P, L the length of the rod, A the sectional area, and C the constant, we have $E = \frac{P \times L \times C}{A}$. Putting M for the coefficient or modulus of elasticity, $M = \frac{1}{C}$; and the equation becomes $E = \frac{P \times L}{A \times M}$

The modulus of elasticity is the weight, which acting upon the unit of surface, and the unit of length, would produce an elongation equal to unity, or the weight, which would stretch a rod, having a sectional area equal to unity, to double its length. In English measures, the modulus of elasticity, or coefficient of elasticity, is therefore the weight in pounds, which would stretch a rod having a sectional area of 1 in. to double its length. Practically, this condition could not exist, for it would be impossible to stretch a rod to double its length without breaking it. As an example, let it be required to find the amount of elongation which a bar, 3 in. in breadth, ½ in. in thickness, and 20 ft. in length, would undergo when strained with a weight of 20 tons. From the equation we have $E = \frac{20 \times 12 \times 20 \times 2240}{1 \cdot 5 \times 24000000} = 0 \cdot 298$ in. A simple rule, which will reduce the labour of calculation, is the following;—Multiply the weight in tons by the original length of the bar in feet; divide the product by the sectional area of the bar, multiplied by the constant 893, and the quotient will be the required elongation in inches. It was proved by the experiment represented in Fig. 5374, that the elongations of the rod were proportional to the weights applied. This is the general law of elasticity, known as Hooke's law, under the title of 'ut tensio sic vis,' and signifies that the extension is proportional to the force applied. Without questioning the abstract truth of this law, it is sufficient to know that within certain limits, it is practically true for all purposes of construction. Under ordinary circumstances, some materials, after being subjected to a considerable tension or compression, will not return to their original length, but will undergo a permanent alteration in that direction. This alteration is called a set, and its amount depends upon the force applied, and the nature of the material. For example, when a bar of iron is subjected to its safe working load only, there is no appreciable set, but as it is necessary to test bars, in order to ascertain the quality and strength of the iron, a heavy tensile strain must be applied, and the set is, to some extent, an indication of the character of the material.

Care must be taken that the testing is not overdone, for if the strain is too great, and the set of a corresponding magnitude, the elasticity of the iron is injured, and the bar rendered useless. There are some peculiarities attending the set of iron. It is not produced instantaneously, but some time is required for it to acquire its full amount, due to a given weight or strain. When this has taken place, and the weight been removed, the second application of it, or of any smaller weight, will not always produce a further set. But if a weight greater than the first be applied, the bar will undergo another elongation or set, due to the greater strain upon it. A certain duration of time appears to be necessary to enable a body to adapt itself to a given strain, for if a heavy weight is rapidly and suddenly applied, it will break at once, without evincing any set. The strain is induced so suddenly that the elastic reaction has no time to exert itself. For each modulus of elasticity, or coefficient of elastic tension, of a material, there will be a corresponding coefficient of elastic compression. These two, although not quite identical, may be considered so, without sensible error, for wrought, but not for cast iron. In round numbers, 10,000 tons may be assumed as the modulus of elasticity of wrought iron, both in tension and compression. After being once stretched, cast-iron bars will sometimes take another set on the re-application of the force, but experiments of this nature are of little practical utility.

In Table I. are given the coefficients of the elastic tension, or moduli of elasticity for different materials, according to the best authorities. Care must be taken that, in all experiments undertaken to determine the modulus of elasticity of any material, the material must not have been subjected to a previous strain of any consequence, or the results will not be reliable. Vitreous materials do not undergo any set, but break at once when the strain is sufficiently great, and Hooke's law does not apply, practically, to some descriptions of stone under compression. Elasticity of volume, or cubic elasticity, is possessed by solids, but this feature does not enter into the consideration of the strength of materials. Fluids possess elasticity of volume only, and not of form. A distinction must be made between the absolute elasticity of a substance, that is, the exactness with which it returns to its original form after being stretched, and the degree to which it may be stretched before it breaks. The amount of play, or range of its elasticity, must not be confounded with the elastic force itself. An ordinary band of india-rubber has a much greater range of elasticity than a similar ring of glass, but india-rubber, nevertheless, does not return to its original form, after being strained, with the same exactness as glass.

TABLE I.—MODULI OF ELASTICITY IN LBS. A SQUARE INCH.

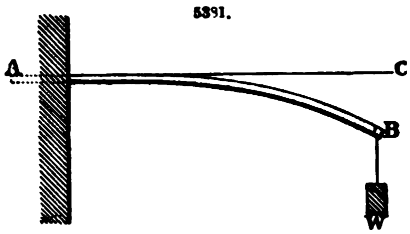
Material.	Modulus.	Material.	Modulus.
Acacia	1,152,000	Norway spar	1,457,600
Ash	1,622,400	Oak, Adriatic	974,400
Beech	1,351,500	„ African	2,305,400
Birch	1,644,900	„ American red	2,150,000
Box, Australian	2,155,200	„ Canadian	2,148,800
Brass, cast	9,050,000	„ Dantzic	1,191,200
„ wire	14,230,000	„ English superior	1,451,200
Copper, wire	17,000,000	„ „ inferior	873,600
Elm	1,019,920	„ European	1,475,000
Fir, red pine	1,680,000	Pine, pitch	1,225,600
„ spruce	1,600,000	„ red	1,520,000
„ larch	1,130,000	„ American yellow	1,600,000
„ Mar Forest	792,480	Poon	1,689,600
„ New England	2,191,200	Slate, Welsh	15,800,000
„ Riga	1,059,600	„ Westmoreland	12,900,000
Glass	8,000,000	„ Scotch	15,790,000
Greenheart	2,665,400	Steel	29,000,000
Gun-metal, copper 8, tin 1	9,886,500	„	42,000,000
Iron, cast	12,177,000	Stone, Portland	1,533,000
„ wrought, plates	24,000,000	Spotted gum, Australia	1,942,000
„ bar	28,350,000	Stringy bark „	1,375,000
„ wrought, wire	25,300,000	Teak, Indian	2,400,000
„ „ „ rope	15,000,000	„ African	2,300,000
Lead, cast	720,000	Tin, cast	4,608,000
„ sheet	720,000	Whalebone	820,000
Mahogany	1,425,000	Zinc, cast	13,680,000
Marble, white	2,520,000		

Elasticity of Torsion.—If an elastic rod, or thread, is fixed at one end and twisted at the other it will exhibit a reaction, which will tend to untwist it, and be proportional to the angle through which it is twisted. In other words, the angle of torsion is proportional to the force of torsion. If, moreover, different lengths of the same rod be subjected to the same force, the angles of torsion will be proportional to the lengths. Again, in the case of cylindrical bars, if the radii is represented by 1, 2, 3, 4, the respective angles of torsion will be equal to θ, $\frac{\theta}{16}$, $\frac{\theta}{81}$, $\frac{\theta}{256}$; so that the angle of torsion is inversely proportional to the fourth power of the radius of the rod. When acted upon by the same force, different substances will twist through different angles, and each substance will have a particular coefficient of torsion belonging to it. If we put this equal to T, make P equal to the moment of the forces acting upon the rod, L its length, R the radius, and θ the angle of torsion, the general equation is $\theta = \frac{P \times L}{T \times R^4}$. Coulomb's experiments proved the truth

of these laws of torsion. A prism undergoes a strain of torsion when a cross-section of it, in relation to another cross-section indefinitely near to it, turns round the axis of the prism. The exterior forces acting upon it tend to twist it round its axis. The angle of torsion is the angle which two originally parallel lines, passing through the respective centres of the two cross-sections of the prism, indefinitely near to each other, make between them, after the distorsion of the prism. This subject will be again referred to when we come to the resistance of materials to a strain of torsion.

Elasticity of Flexure.—If a rod A B of any material has one end fixed in a wall, as represented in Fig. 5381, and a weight W suspended at the other end, which is free, it will deflect below the horizontal line A C, and take the curved form shown in the figure. The rod will deflect until its elastic reaction makes equilibrium with the weight W. When the rod is in this position, the fibres on its upper surface are extended, and those on the lower compressed or shortened. If the weight be removed, the forces which are developed in the rod by the strain upon the fibres will cause it to return to the horizontal line A C, provided the weight applied has not exceeded the limits of elasticity of the material. The cathetometer may be employed to measure the amount of the deflection of the rod below the horizontal line A C. By adjusting the instrument so as to sight the two extremities A and B, the difference of level between them, which is the deflection of the rod, can be accurately determined. If θ equal the arc which the free end of the rod describes, the deflection is proportional to the arc. Let the rod be of uniform section throughout; let L = the length, B the breadth, D the depth, and C a constant, varying with the material, then the flexure F will be given

5381.



by the equation $F = \frac{P \times L^3}{C \times B \times D^3}$. There are some solid bodies which exhibit no elasticity under any conditions, and may justly be considered altogether devoid of that property. Wax, when soft, clay, putty, and many similar substances come under this category, and are termed plastic. There are some other properties belonging to bodies which affect their strength, such as toughness, stiffness, or brittleness. Toughness is that quality in a body which enables it to undergo, without breaking, sudden and considerable changes of form, and is opposed to brittleness. Certain descriptions of timber and iron are very tough, whereas glass and highly-tempered steel are very brittle. The latter have no ductility. They will not stretch under a suddenly applied strain, but snap off short at once. Toughness is the desirable quality to impart to a body which is intended to be subjected to a strain of torsion. The term stiffness is frequently employed synonymously with that of toughness, but the former is more correctly used in relation to the strength of materials, considered with reference to their resistance to flexure. If there are two pillars of different material, but of the same dimensions, the one which deflects less under a given load is said to be stiffer than the other.

Classification of Strains.—All the strains to which bodies are subjected may be classed under one of two heads. They tend to destroy the body, either by compression or extension. Eventually, if the strain is carried to the breaking point, the fibres of the body will be either shortened or lengthened. For the sake of distinction, however, the strains upon bodies are usually classed under five subdivisions, and are—1. A strain of compression; 2. Of tension; 3. A transverse strain; 4. A shearing strain, or strain of detrusion; 5. A strain of torsion. These are thus explained;—A body is under a compressive strain when it is pressed in the direction of its length, as in the case of columns, posts, and rafters. It is tensilely strained when a stretching force is similarly applied to it in the direction of its fibres. Ropes, cables, king-posts, tie-beams, and the lower chords of timber bridges are familiar examples. A transverse strain tends to break a body across, in a direction either perpendicularly or obliquely to its length, as in the case of joists, beams supported either at one or both ends, and all classes of levers. A body is under a shearing strain, or strain of detrusion, when the strain tends to cause the particles to slide on one another along the plane of fracture. Examples are to be found in the rivets of ironwork, in punching machines, and in the ends of tie-beams, into which the feet of the rafters are mortised. A strain of torsion tends to wrench or twist the body, with a force acting in a direction perpendicular to some part of its length, as for instance in the axles of fixed wheels, the driving shafts of machinery, and the levers of presses.

Compressive Strength of Materials.—Taking the strains in the order of their enumeration, we commence with that of compression. The compressive strength of any material, under certain conditions, is directly proportional to its sectional area. The exceptions to this rule are the case of long pillars, and every instance in which the strain is no longer that of a simple thrust, but complicated by the addition of one of a transverse character. All bodies acted upon by a compressive strain may be termed struts, in contradistinction to ties, which undergo a strain of tension. Strains of compression and tension are of opposite character. The former are denoted by the sign + and the latter by −. Struts have different names given to them, according to the position they occupy in a structure, and the manner in which they support their share of the load. An upright strut is a post, column, or pillar; a slanting one a rafter, stay, or jib. As a body under a compressive strain may yield in one of two ways, either by being actually crushed, or partly through crushing and partly by flexure, it will be convenient to treat them separately. Experiment has proved that when the lengths of pillars of any given material are not less than one and a half, and not more than four or five times, the diameter which is constant for all of them, their respective strengths are practically the same. The crushing strength of any material is the weight which would just crush a prism, having a base of 1 sq. in., and the height of which is within the

limits of one and a half, and five times the diameter. Putting A for the sectional area in inches of a pillar of these proportions, and C for the crushing strength found by experiment for the given material, the value for S, the strength of the pillar is $S = A \times C$. When A = the unit of area, $S = C$, and the strength of the pillar is equal to the unit crushing weight. This simple rule would be universal in its application, independently of the length and diameter of the pillar, if we could ensure the line of pressure always coinciding with the axis of the pillar. But this is not possible, and since the absence of this coincidence is the cause of the bending of the pillar, we must have recourse to other rules for determining their strength. The fracture of short specimens of timber, iron, and stone always takes place by a wedge-shaped fragment splitting off at an angle with the base, and this angle is approximately constant for pillars of the same material. In all experiments undertaken with the object of determining the crushing strength of materials, the line of pressure must be made to coincide with the longitudinal axis of the prism under trial, and moreover, the pressure must be uniformly distributed, or the results will not be reliable. The neglect of these precautions has rendered many otherwise valuable experiments of no use whatever. Great care must likewise be used in placing dependence upon results obtained from experiments upon very short specimens, mere cubes in fact. This was a great error, fallen into by the early experimenters on the compressive strength of materials. When the line of pressure upon a column departs considerably from the longitudinal axis, the pillar becomes very much weakened. There is evidently greater probability of a solid pillar yielding from this cause than a hollow one, containing the same quantity of material. In the latter instance the diameter can be increased, so that if the line of pressure deviates from the axis of the pillar, it will not be so likely to pass outside the circumference. When timber or stone is used in the position of a pillar or strut, the safe position of the line of pressure is usually ensured by giving them such dimensions as will effectually confine it within them. Pillars of metal are sometimes solid when their diameter is comparatively small, but more generally hollow.

There are several forms or sections in which iron can be obtained ready rolled in the market, which are exceedingly well adapted to resist strains of compression. They are well known to engineers as angle, tee, channel iron, and others. Angle iron is a convenient section for the compression bars, in the web of lattice and other types of bridge girders of moderate span, and presents, when of small scantling, greater facilities than the other sections for riveting. Tee iron is a useful form for the same purpose, when it can be used of sufficient size to take rivets on each side of the rib. The handsomest form of strut is channel iron, and also a very strong one. It is used for the compression bars in the web of the main girders of the London, Chatham, and Dover Railway bridge over the Thames at Blackfriars, but the effect of its appearance is lost by the ribs being turned inside, so that the struts appear to be plain bars, like the ties. In Table II. is given the value of C, or the coefficient of the ultimate, or crushing, strength, for different materials, in lbs. a square inch.

TABLE II.—COEFFICIENTS OF ULTIMATE, OR CRUSHING, STRENGTH IN LBS. A SQUARE INCH.

Material.	Value of Coefficient.	Material.	Value of Coefficient.
Alder	6,960	Iron, cast	96,410
Ash	9,180	„ wrought	37,250
Baywood	7,520	Larch	5,550
Beech	9,240	Lead	7,000
Birch, American	11,660	Limestone, compact	7,710
„ English	6,100	„ Purbeck	9,160
Brass, cast	10,300	„ Anglesea	7,580
Brick, light red	640	„ Dublin	16,940
„ dark „	950	Mahogany, Spanish	8,100
„ fire, Stourbridge	1,710	Marble, Italian	9,680
Brickwork in cement	1,000	„ Devonshire red	7,430
Cedar	5,730	Oak, American red	6,000
Cement, Portland	3,795	„ Canadian	6,000
Chalk	450	„ Dantzic	7,720
Copper, cast	11,700	„ English	10,030
Crab	7,150	Pine, pitch	6,790
Deal, red	6,590	„ red	6,660
„ white	7,300	„ yellow	5,430
Elder	9,970	Poplar	5,120
Elm	10,210	Portland stone	4,000
Freestone, Craigleith	5,490	Sandstone, Bramley Fall	6,060
Fir, red pine	5,790	„ Yorkshire paving	5,714
„ American yellow	5,400	„ red Runcorn	2,185
„ spruce	6,820	„ Quartz rock, Holyhead, across lamination	25,500
Glass, flint	27,590		
„ common green	31,880	„ parallel to lamination	14,000
„ white crown	31,000	Steel, cast	225,570
Granite, Aberdeen	10,910	Slate	11,000
„ Peterhead	8,280	„ Irish, average	16,660
„ Cornish	6,360	Teak	12,050
„ Dublin	10,450	Tin	15,000
„ Mount Sorrel	12,860	Walnut	7,230
Greenstone, Giant's Causeway	17,220	Whinstone, Scotch	8,270
Hornbeam	7,150	Willow	6,130

In the values given in Table II. of the coefficients of ultimate strength, relative to the crushing weight of different kinds of timber, the material is supposed to be thoroughly dried. In some kinds of timber, the strength of a wet specimen is only half that of a dry one. As an example of the strength of a short pillar, let it be required to ascertain what weight in tons will crush a piece of beech 3 ft. long and 9 in. square. Let W equal the crushing weight in tons, and A the area of the section; then $W = \frac{A \times 9240}{2240} = \frac{9 \times 9 \times 9240}{2240} = 334 \cdot 12$ tons. Again, what weight in tons will crush a solid short pillar of cast iron 1 ft. 6 in. in length and 4 in. in diameter. Here

$$W = \frac{0 \cdot 7854 \times 96410 \times 16}{2240} = 540 \cdot 86 \text{ tons.}$$

Classification of Pillars.—We have now to consider the case of columns, in which the ratio of the length to the diameter exceeds the limits of $5\frac{1}{2}$ or 6 to 1, and they become long columns, and their strength is calculated by a different rule. Two cases for investigation here present themselves; one in which the pillar is so long that it fails altogether by flexure, like a beam under a transverse strain, and its breaking weight falls far short of the value of that required to crush a short pillar. The other case includes all pillars which, although they fail ultimately by deflection, yet their length is such, that their breaking weight approaches much nearer to that which would crush a short pillar than in the former case. The three classes of pillars therefore are;—First, short pillars, which fail by crushing. Secondly, long pillars, which fail by flexure. Thirdly, intermediate pillars, which fail partly by crushing and partly by flexure. Long pillars of cast iron are those whose length is at least thirty times their diameter, if both ends are flat, and at least fifteen, if both ends are rounded. In all long pillars, the resistance to breaking, when the pillar is firmly bedded, is three times that when the ends are rounded and capable of motion. If one end of a pillar be flat, and the other rounded, its strength is the mean between that of a pillar with both ends rounded, and of one with both ends flat. The relative strengths of three cylindrical pillars, the first having both extremities rounded, the second one rounded and one flat, and the third both flat, are as 1, 2, and 3. Moreover, if the ends of a pillar are firmly fixed, its power to resist breaking is equal to that of a pillar having the same diameter and half the length, and with the ends rounded, so that the strain passes through the longitudinal axis. The rule for calculating the strength of solid cast-iron long columns, or those in which the length is more than thirty times the diameter, and when the ends are flat and fixed, is as follows;—Put D for the external diameter in inches, L for the length in feet, and W for the breaking weight in tons; then, $W = 44 \frac{D^{3 \cdot 6}}{L^{1 \cdot 7}}$. *Example.*—What is the breaking weight of a solid cast-iron pillar 10 ft. long and 3 in. in diameter, with ends flat and fixed? Here $W = \frac{44 \times 3^{3 \cdot 6}}{10^{1 \cdot 5}} = 44 \times \frac{52}{50} = 45 \cdot 76$ tons. When the column is hollow, and under similar conditions, putting D and d for the external and internal diameters respectively, $W = 44 \frac{D^{3 \cdot 6} - d^{3 \cdot 6}}{L^{1 \cdot 7}}$. In the original investigations of Hodgkinson, who is the great authority upon this subject, the common factor is not quite the same in the two formulæ, but the discrepancy is practically of no consequence, and it simplifies the calculations. For solid long columns of wrought iron, in which the length exceeds sixty times the diameter, we have $W = 134 \frac{D^{3 \cdot 6}}{L^2}$. *Example.*—To find the value of W for a solid wrought-iron pillar 4 in. in diameter and 10 ft. long, we have $W = 134 \frac{4^{3 \cdot 6}}{10^2} = 134 \frac{147}{100} = 196 \cdot 98$ tons. Columns of wrought iron of this description are considerably stronger than similar pillars of cast iron, as may be inferred by calculating the strength of a similar column of the latter material, for which we have $W = 44 \frac{4^{3 \cdot 6}}{10^{1 \cdot 7}} = 44 \frac{147}{50} = 129 \cdot 36$ tons. For solid long square columns of dry Dantzic oak, in which the length exceeds thirty times the diameter, putting B for the length of the side, $W = \frac{11 B^4}{L^2}$; and for similar columns of dry red deal, $W = \frac{7 \cdot 8 B^4}{L^2}$. If the ends of the above pillars are rounded, and the ratio between their lengths and diameters halved, their respective breaking weights will equal approximately $\frac{W}{3}$. Representing the strength of a long cast-iron column by unity, that of similar columns will be as follows;—Cast steel, 2·5; wrought iron, 1·7; Dantzic oak, 0·1; Memel, 0·08. By Gordon's rule, putting L for the length in inches, S for the sectional area in inches, C and F for constants, and the rest of the notation as before, we have the general formula $W = \frac{C \times S}{1 + \frac{F L^2}{D^2}}$, and for the breaking weight of round cast-iron hollow columns $W = \frac{36 S}{1 + \frac{L^2}{400 D^2}}$. If the section be a hollow square, and D the diagonal, $W = \frac{36 S}{1 + \frac{3 L^2}{800 D^2}}$. When the section is a cross, and

D the length of the diameter, from end to end of the shortest pair of arms, $W = \dfrac{36\,S}{1 + \dfrac{3\,L^2}{400\,D^2}}$.

When the ends are hinged, take 100 D^2 instead of 400 D^2 and 200 D^2 instead of 800 D^2, in these formulæ. J. T. Hurst gives the following rules for columns of wood, with ends flat and fixed, when D = the diameter in inches, L the length in feet, S the sectional area in inches, and W the breaking weight in tons. For round columns, $W = \dfrac{C \times S}{1 + \dfrac{L^2}{2\,D^2}}$. For square or rectangular columns, $W = \dfrac{C \times S}{1 + \dfrac{L^2}{4\,T^2}}$; when T is the side or least thickness in inches. The values of C for different woods are here given;—

Teak	4·5	Canadian oak	2·9
English oak	4·0	Spanish mahogany	2·5
Baltic oak	3·7	Baltic fir	2·5
Beech	3·0	American pine	2·4

When the pillars are of angle iron, tee, channel, or H section, the values of C and F in Gordon's formula are $C = 19$ and $F = \dfrac{1}{900}$

The following facts obtain with regard to long columns. The addition of discs to cast-iron columns, affords practically no increase of strength. Long cast-iron pillars, with both ends rounded, break only in the middle. With both ends flat, they break at the middle, and near each end. With one end rounded, and one flat, they yield at about one-third of the distance from the rounded end. No additional strength is given to hollow pillars, by enlarging the diameter at the middle, but a slight increase is given to solid pillars, especially if the ends are rounded. Solid square pillars break transversely, in a direction nearly parallel to their diagonals. If a long pillar is so insecurely, or defectively fixed, that the line of pressure lies in the direction of the diagonal, instead of the axis, its strength is only one-third of that which it would be, if properly fixed. The strength of similar long pillars is nearly in the ratio of their transverse section. As an example. What is the breaking weight of a hollow cast-iron column, having a length of 10 ft., and external and internal diameters of 4 and 3 in. respectively? By the formula

$$W = 44\,\frac{D^{3\cdot6} - d^{3\cdot6}}{L^{1\cdot7}} = 44\,\frac{(147 - 52)}{50} = 83\cdot6 \text{ tons.}$$

An intermediate pillar, if it is of cast iron or timber, is one whose length is less than thirty times its diameter, and if of wrought iron, less than sixty times the diameter. To find the breaking weight of an intermediate solid pillar, with both ends flat and fixed, let W = the breaking weight found by the formula for long columns, A the sectional area of the pillar in inches, C the coefficient of crushing, and W_1 the breaking weight in tons of the intermediate pillar, then $W_1 = \dfrac{W\,A\,C}{W + 0\cdot75\,A\,C}$. The strength of intermediate pillars with flat ends varies from three to one and a half times that of those with rounded ends, or less, according as the number of times which the length exceeds the diameter, is reduced. The strength of those with one end round and the other flat, is nearly an arithmetical mean between the strengths of the other two, whatever their proportion might be. A slight inequality in the thickness of hollow pillars at different parts does not much affect the strength. If the specified thickness be put equal to T, then the range lies between 0·75 T and 1·25 T as the extremes. The relative strengths of long solid pillars of different cross-sections, but having the same length and weight, and of the same quantity of material, are square pillar = 0·93; round = 1·00; and triangular = 1·10. In hollow pillars of wrought iron, when the proportion of length to width is as 15 or 20 to 1, the strength is practically independent of the length. Round tubular pillars of wrought iron are stronger than those of a rectangular form, the thickness of both being uniform. The strongest form of timber pillar is the square, the quantity of material, and the length being constant. If L be the length of a long, round, or square timber pillar, and D the diameter, the strength is nearly as $\dfrac{D^4}{L^2}$. Were the material absolutely incompressible, the strength would be represented by that proportion, which is the equation of Euler.

In the experiments made on stones of different kinds, the strongest were found to be the basalts, slates, and primary limestones. Sandstones vary considerably in strength. It appears from the experiments of Vicat, that if a column is built up with only horizontal joints, that is, each stone constituting a course in itself, its crushing strength is nearly the same as if it were a monolith. The beds and joints are supposed to be the best of the kind. The strength of cylinders in motion, between two horizontal planes, is proportional to the product of their diameter and axis. The strength of spheres to resist crushing, is as the square of their diameters. Moreover, representing the strength of a cube by unity, that of the inscribed cylinder on its base will be 0·80; that of the same cylinder on its side 0·32, and that of the inscribed sphere 0·26. When a body undergoes a strain of compression, when it is inclined at an angle to the horizon, the strain upon it is greater than when it is in a vertical position. Generally, the equation is, putting W for the load, θ for the angle of inclination to the horizon, and S_1 for the actual strain, $S_1 = W \times \text{cosec.}\,\theta$.

The strength of braced pillars is, within certain limits, independent of their length. B. B. Stoney concludes, from an experiment made on one of the braced struts of the Boyne Viaduct, that the strongest form for a hollow rectangular pillar, is that in which the greater part of the material is collected at the angles, in which case, the angles act similar to the flanges of a girder, and the thin plates as the web.

Tensile Strength of Materials.—The strength of materials with respect to a strain of tension has now to be considered. The tendency of a strain of tension, upon any material, is to pull it perfectly straight from end to end. It is independent of the length of the body, constant throughout it, and inversely proportional to the sectional area, provided the area is uniform, and the same precautions are observed in the application of the strain, as in the case of bodies under compression. If T is the coefficient of the ultimate tensile strength of 1 sq. in. of any material, and A its sectional area, then the breaking or tearing weight is equal to $A \times T$. A bar under a strain of tension, in comparison with one under a strain of compression, may be said to be in a state of stable equilibrium, while the bar under compression is in a state of unstable equilibrium. If we imagine a bar in tension to be deflected by any extraneous force, the tendency of the strain acting upon it is to pull it straight again, and to restore it to its original condition of equilibrium. But if a bar in compression is placed under similar circumstances, the tendency of the strain upon it is to increase its deflection. The operations of the furnace and the foundry have a very considerable influence upon the tensile strength of cast iron. Considered as a material for construction, cast iron is not suited to undergo strains of a tensile character. Wrought iron and steel are to be preferred to it in all cases. With respect to the tensile strength of these two materials, the results arrived at by Kirkaldy are exceedingly valuable. From them we learn that the breaking strain of both wrought iron and steel is no certain test of their quality. The true test is to be found in comparing the breaking weight with the contraction of area at the time of fracture. The popular opinion that a rough bar is stronger than a turned one of the same sectional area, is a fallacy.

When iron is broken suddenly, it always presents a crystalline appearance, but when slowly, a fibrous one. The more iron is rolled and worked, the less likely it is to break suddenly. When steel is fractured suddenly the appearance is granular, and devoid of the brilliancy which attends the fracture of wrought iron under the same conditions. When it is broken slowly, the appearance is fibrous and silky, and the line of fracture is not at right angles to the length. Steel is reduced in tensile strength by being hardened in water, but greatly increased in both tensile strength and toughness by being hardened in oil. The specific gravity of a specimen is a good test of its quality. Instead of the density of iron being increased by the process of wire drawing and cold rolling, as supposed, it is decreased. The strength of iron plates, when stretched in the direction of their length, is about 10 per cent. more than when stretched at right angles to the length. Bars are stronger than plates, although the difference appears to depend, in some measure, upon the scantlings of the bars. Annealing iron diminishes its tensile strength, but at the same time improves its ductility and toughness. When old chains are bought to be used again, they should always be annealed. When commencing the erection of the Albert Bridge, the contractor's engineer, F. W. Bryant, had every chain and rod of iron passed through the fire before employing them in the works. The use of steel is not so general as it ought to be, considering the great tensile and compressive strength of the material. This is owing to the great uncertainty that attends its manufacture. In a given number of specimens, some are all that could be wished, while others are so hard and brittle that they are of no use whatever. Manufacturers should bear in mind that great tensile strength is not always the chief desideratum in a constructive material; other qualities, such as ductility and toughness, are frequently of quite as much, if not of more, importance.

TABLE III.—COEFFICIENTS OF ULTIMATE, OR TEARING, STRENGTH IN LBS. A SQUARE INCH.

Material.	Value of Coefficient.	Material.	Value of Coefficient.
Acacia	16,000	Fir, red pine	13,000
Alder	13,900	„ spruce	12,400
Ash, average	16,000	Glass, flint rod	2,400
Beech	11,350	„ common green	2,900
Birch, American	15,000	„ white crown	2,500
Box	20,000	„ plates	5,000
Brass, cast	18,000	Gun-metal	36,300
„ wire	91,000	Hornbeam	20,000
Brick	290	Iron, cast	16,550
Brickwork in mortar	50	„ wrought rolled bars	57,500
„ „ cement	280	„ „ plates	50,700
Cedar	11,200	„ „ wire	85,000
Cement, Portland	270	Jugeb	18,500
„ Roman	190	Larch	10,000
Chestnut, Spanish	13,300	Lancewood	23,400
Copper, bolts	47,900	Lead, cast	1,820
„ cast	19,000	„ sheet	1,920
„ sheet	30,000	Mahogany, Spanish	16,000
„ wire, not annealed	77,500	Maple	10,500
„ „ annealed	32,100	Marble, Italian	720
Cordage	8,600	Mortar, ordinary	50
Deal, Christiana	12,000	Oak, American red	10,250
Elder	10,000	„ Black bog	7,700
Elm	13,650	„ Canadian	10,000
Freestone, Craigleith	450	„ English	17,000

TABLE III.—COEFFICIENTS OF ULTIMATE STRENGTH—*continued.*

terial.	Value of Coefficient.	Material.	Value of Coefficient.
Pine, pitch	7,650	Teak, Indian	15,000
„ red	12,000	Tin	4,750
„ yellow	11,000	Walnut	8,130
Poplar	5,500	Whinstone, Scotch	1,450
Steel, bars	97,800	Willow	12,500
„ plates	85,150	Yellow metal, patent	49,200
Slate	11,200	Yew	8,000
Sycamore	13,000	Zinc	7,700
Teak, African	21,000		

In Table III. of the value of T, the coefficients of the tearing strain of different materials, the coefficients for the various kinds of timber are calculated on the assumption that the strain is applied in the direction of the length of the specimens. It is necessary to observe this distinction, as the tensile strength of timber, when the strain is applied across the grain, is very much less than when it is applied in the direction of the length. For instance, the tensile strength of fir is reduced to 690 lbs.; that of larch to 1335 lbs., and that of oak to 2300 lbs. for each square inch of section.

Chain Cables.—Of all bodies subjected to tensile strain, chain cables are those which are most severely tried. There are three principal kinds of chains and chain cable, including close-link chain, stud-link chain, and long-link chain without studs. Upon the authority of Brown, Lennox, and Co., the average breaking strain of stud-link chain of good quality is equal to 17·28 tons a square inch of each side of the link. In converting a bar into a link, it loses more than 30 per cent. of its original strength. The Government proof test for stud-link chains is equal to 11·50 tons a square inch of each side of the link. The Admiralty proof test for close-link chain is equal to 7·60 tons for the same unit of area. A close-link chain, having a diameter of 1 in., is as strong as a machine-made rope, having a girth of 10 in., their relative weights being as 3 to 1 nearly. With respect to long-link chains, Stoney observes, "The links of long-link chains are not oval like those of a stud-chain, but parallel-sided, and an open-link chain, of the same length of link as a stud-chain, is lighter by the weight of the studs. It is suited for moorings of a permanent character, such as those of harbour mooring buoys, beacon buoys, or light-ships, which are seldom shifted, and where consequently flexibility is a secondary object. Besides its comparative lightness, long-link chain has another advantage over either close-link or stud-chain, for each 15-fathom length of the two latter requires long open links at the ends, for the purpose of connecting it by shackles to the adjoining lengths, and if one of these chains break, a whole length must be taken out, since there is not room for a shackle to pass through the ordinary close-link or stud-link. When, however, a long-link breaks, the links adjoining the fracture can be connected together, without taking out a whole 15-fathom length, as a shackle will pass through any of the long links. The Admiralty proof for large open long-link chain without studs is 315 lbs. a circular ⅛ of an inch, or one-half the proof of stud-chain." The proof test, used by the Trinity Board, for cable chains intended for moorings, is equal to 8·50 tons a square inch of each side of the link. A link is also cut out, here and there, to show the quality of the iron, as the resistance to a tensile strain is no proof of the toughness and other desirable qualities in the material.

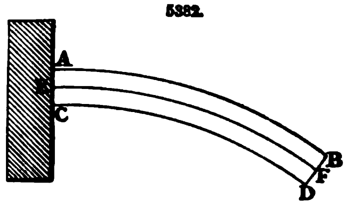
As to the comparative strength of stud and close-link chains, Brown, Lennox, and Co. remark, "We are not of opinion that studs increase the strength of chain, or enable it to bear a heavier ultimate breaking strain, than if made without them, both descriptions being made of the same length of link. The object of their being used is to prevent collapse of the link, which, in open-link chain, takes place at a strain considerably below the breaking strain, and, of course, renders the chain unserviceable. They thereby enable chains made with them to be used for heavier strains than open-link, but do not add to their ultimate strength; indeed, from the experiments we have tried, and the experience we have had, we are inclined to believe that the link without stay pins, almost invariably breaks at a higher strain than stud-chains. The proof for studded chain is the higher, only because a sufficient proof cannot be given to open-link chain before the link spoils its form and becomes rigid. The stay prevents collapse, by which the link is prevented elongating so much, and taking its natural position, before its utmost power is exhausted, and a break ensues. The link, if sound in the workmanship, will nearly always break near the stay pin, which is caused by the nip across the stay pin. If made without stays, it will collapse until it is rigid, and the iron will reach as near as possible the direct line of the strain, or right through the centre of the chain; the sides of the link will incline inwards, and the break will ensue at the nip across the crown of the next link. In connection with the subject of tensile strain, there is a curious relation between it and the pitch of musical notes in a piano, or other stringed instrument. Let W be the straining weight in lbs.; W_1 the weight of wire between the bridges; L the length of the wire in inches; V the number of vibrations in a second, and N the number of inches in a second's pendulum; then $W = \frac{W_1 \times V^2 \times L}{N \times \pi^2}$.

Wilfred Airey has applied this principle to ascertain the tensile strains in the bars in the web of bowstring girders. The process by which the tensions were ascertained is both novel and ingenious, and is as follows:—The ties in the model girder were constructed of thin steel wire, and on being sounded gave a good resonant musical note. Advantage was taken of this to compare the note of any given string in the girder, with that of a free string suspended in a frame made for the purpose, and the length of which could be adjusted, so as to equal that of the string in the girder under comparison. The length having been adjusted, a small scale span was suspended from one end of the free string, and weights gradually placed in it, until the note of the free string

exactly coincided with that of the string in the girder. This was determined by ear with the greatest accuracy, the effect of 0·5 oz. in 80 oz. being clearly perceptible. Consequently the tension of the string in the girder was measured by the weight in the scale pan of the free string, and this was done for every string in the girder. The determination of the thrusts, which first appeared a great obstacle, was reduced to that of determination of tensions by the following expedient;—It was observed that the effect of a uniformly distributed load was to throw all the strings into tension. The girder was therefore loaded with a heavy uniform load, and the travelling load was then applied in addition. The effect of this travelling load would be to increase the tension of some of the strings and to diminish that of others, but so long as the tension on every string, produced by the stationary load, was greater than the thrust produced by the travelling load, the string would remain in tension, and its tension could be estimated as described. Consequently it will be seen that the recorded tensions and thrusts, which would be produced by a single weight at various distances along the girder, are the results of a differential process. Thus a uniformly distributed load is applied on the girder and the tension of every string ascertained. Then a travelling weight is introduced in addition, and hung at any one point, and the tension of every string is again taken. The difference of the tensions in the two cases of each string, is taken as the thrust or tension of the string produced by the travelling load.

Transverse Strain.—Of all others, transverse strain is that with which we are most familiar. All materials are comparatively weaker when exposed to a transverse strain, than when subjected solely to either a tensile or compressive strain. This may be possibly due to the more complicated nature of the strain, although its actual results, which are the important points to the engineer, are devoid of all complexity. In the action of transverse strain, strains of both tension and compression are developed in the body, and the phenomenon of deflection comes also into action. If a beam rests upon two supports at its extremities, and a weight is placed at its centre, the beam will have a tendency to deflect. It has not been determined, with respect to any material, what is the smallest weight which would cause an incipient flexure in the beam. The same result will ensue if the beam is fixed at one end and a weight attached to it at the other, as shown in Fig. 5382, an inspection of which will point out that the fibres of the upper or convex surface, A B, are extended, while those on the lower, or concave, C D, are compressed. Between these two surfaces there must evidently be a line, or layer of fibres, which are neither extended nor compressed, but which remain, so far as their length is concerned, quite unaffected by the strain. The exact position of this line E F, or of the layer of unaffected fibres, is, in some instances, a work of great labour to determine, but its approximate position, in those forms of beams and girders usually met with in practice, can be ascertained sufficiently accurately for all practical purposes. If a horizontal plan is drawn through the line E F, so as to leave exposed a plan of the layer of invariable or unaffected fibres, then that plan represents the neutral surface of the beam, since it contains all the fibres unaltered in length. The line E F is therefore the longitudinal elevation of the neutral surface, or the line representing the curve of the unaffected fibres. If a cross-section of the beam is made at any point, it will cut the neutral surface, and the intersection will give the line E F in Fig. 5383, which is the neutral axis of the cross-section A B C D of the beam. Very great influence upon the strength of a beam is exercised by the position of the line E F, in the cross-section, and the arrangement of the material relatively to it, determines the proper forms to be adopted for girders. A vertical longitudinal plane, M N, in Fig. 5384, drawn through the centre of the beam, will intersect the neutral surface, and cut all the neutral axes in the point P, which may be called the neutral point for any given section. The relations between neutral surface, line of curve, and neutral axis, are those of plan, elevation, and section, as shown in Fig. 5385.

5382.



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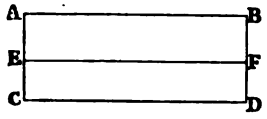

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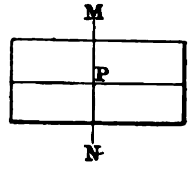

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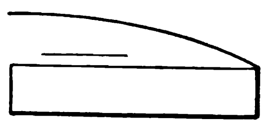
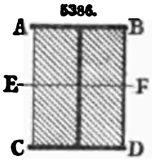


The straining weight is supposed to act at right angles to the longitudinal axis of the beam, both before and after bending takes place. Mathematically speaking, it cannot fulfil both these conditions, but if the first is ensured, the second may be assumed to be so also. If, moreover, the resistance of the material to tension and compression is considered identical, which may be safely done within ordinary limits, the position of the neutral axis in any cross-section of a beam, will coincide with the position of its centre of gravity. Consequently the neutral axis of all the cross-sections, or the neutral line of all symmetrical beams, will pass exactly through their centres, and the neutral line and the longitudinal axis will coincide. The law with regard to the arrangement of the particles about the neutral axis, independently of the nature of the materials, is that each particle, or each layer of fibres, exerts a resistance against a transverse strain, in direct proportion to its distance from that axis. Generally if x is the resistance of any particle situated at a distance y, from the neutral axis, and x_1 that of any other particle at another distance y_1, then their respective moments will be $x \times y$ and $x_1 \times y_1$. The conclusion to be deduced from this fact is that all the material

should be placed as far as possible from the neutral axis, a condition which, when carried out, gives rise to the ordinary flanged girder. If in the solid beam A B C D, in Fig. 5386, the material near the centre is transferred to the top and bottom, the result is the flanged girder, in which every layer of particles in the flanges acts with nearly twice the amount of resistance in the solid beam. The example shown in Fig. 5386 is not to be regarded as indicating the best method of converting the solid beam into a flanged girder, or as the best form of girder, but merely as an illustration of the manner in which the arrangement of the material, with reference to the neutral axis, affects the strength of the body. The correct ratio of the dimensions of the top and bottom flanges respectively, depends upon the nature of the material, and its ultimate resistance to the several strains of tension and compression.

5386.



It was supposed that the neutral axis in beams and girders exposed to transverse strain, shifted its position, but the microscopical examinations of Barlow and those of Brewster demonstrated the contrary. Very recently the same result has been arrived at by Nickerson, an engineer at St. Louis, who made a series of experiments, similar in character to those of Brewster. He employed the principle of the polarization of light, and his apparatus consisted of a polarizer formed of glass plates, an analyzer of plate glass blackened on one side, and a kind of vice of bronze provided with a screw, by means of which a strain of either compression or tension could be brought upon the specimens of glass under experiment. In Brewster's experiments polarized light was transmitted through a small rectangular glass girder about 6 in. in length, 1¼ in. in breadth, and rather more than a quarter of an inch in thickness. When the girder deflected under transverse strain, the neutral axis maintained its position in the centre, while above and below it the evidence of strain was rendered manifest by coloured curved lines. The glass pieces in Nickerson's experiments before being submitted to strain appeared black, since polarized light does not traverse glass in its normal condition, that is, when unacted on by strain or pressure, but so soon as they were placed in the vice, and the screw brought into action, two bright bands or lines appeared on either side of the centre, enclosing a dark space. As the intensity of the pressure was increased, the edges of these bands became more clearly defined, and ultimately took the form of distinct curved lines, corresponding to the lines of equal resistance. They increase in number and brilliancy in the direct ratio of the strain, and as they increase so does the included dark space diminish. The observations prove that the neutral axis is a flexible line which, in a rectangular girder, remains parallel to the upper and lower surfaces, and passes through the centres of gravity of the several cross-sections only when the load is uniformly distributed over the whole length of the girder, or when the length is infinite. On the other hand, when the pressure is local, which is tantamount to a load not uniformly distributed, the neutral axis is more or less influenced in its position and form, from the point of the application of the partial pressure to each point of support. In glass girders in which the length is fourteen times the thickness, the neutral axis is practically horizontal, and even when this proportion is as 10 to 1 the departure from the horizontal line is barely more than just appreciable. It is remarkable that the undulations of the polarized light are limited to two directions at right angles to one another, and that in every experiment two images corresponding to these two directions were produced by rotating the analyzer through an angle of 90°. Nickerson terms one of these the positive and the other the negative image. These images evidently represent the two descriptions of reactions, perpendicular to one another, which are developed in a girder or column when subjected to strain. They may be considered as the shearing strain and the longitudinal strains of tension and compression developed in the flanges of a girder, since each image increased in brilliancy as the strain to which it corresponded was augmented.

A transparent column submitted to a strain of compression presents a series of coloured rings which, when the column is of glass, are congregated in number from three to six at each end. When a softer material, such as copal, is employed, the column is covered with coloured bands, extending from one end to the other. It is to be noticed that the blue and red bands are always separated by a dark space, as in the case of girders, which indicates that this portion of the column is either free from strain, or that there the existing forces equilibrate one another. Before discovering the meaning of the coloured bands, Nickerson made several experiments upon cubes of copper, of which the length was 1¼ in., the external and internal diameters 0·45 in. and 0·35 in. respectively. These tubes suffered deformation under pressure, and when compressed until they assumed a permanent shape, they presented a series of protuberant rings separated by a uniform space and resembling waves. Steel tubes gave similar results. The practical conclusions to be drawn from these experiments is, that the strength of hollow columns can be considerably increased by furnishing them with rings or diaphragms, placed at the points which correspond to the position of the waves in the permanent deformation.

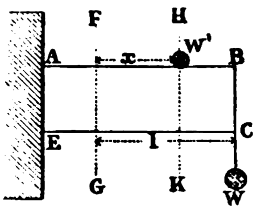
It has been already stated that the resistance, and consequently the strain, upon any two fibres of a beam is proportional to their respective distances from the neutral axis. From this can be readily deduced the total moment of strain upon any beam. Let F be the strain acting upon any fibre, having an area equal to unity, at a distance x from the neutral axis. The strain upon any other fibre having also an area equal to unity, and situated at a distance y from the axis, will therefore be equal to $\frac{F \times y}{x}$, and if its area have any value such as a, the total strain upon it will be equal to $\frac{F \times y \times a}{x}$. The moment of this strain upon the fibre will be equal to the product of the above fraction, and the perpendicular distance the fibre is from the neutral axis, which equals y, and therefore the moment of the strain equals $\frac{F \times a \times y^2}{x}$. If we extend this equation to all the fibres in the cross-section of the beam, and calling M the total moment, we have

$M = \frac{F}{x} \int a y^2$. But $\int a y^2$ equals the moment of inertia of the beam of the given cross-section, which is usually represented by the letter I, so that by substitution in the equation $M = \frac{F \times I}{x}$. The determination by mathematical analysis of the values of I, does not belong to the present subject, but in Table IV. the values of I are given for beams of different cross-sections.

Table IV.—Values of I.

Form of Section.	Value of I.
Solid rectangle	$\frac{B D^3}{12}$.
Hollow rectangle	$\frac{B D^3 - B_1 D_1^3}{12}$.
Solid square	$\frac{B^4}{12}$.
Hollow square	$\frac{B^4 - B_1^4}{12}$.
Solid circle	$\frac{\pi R^4}{4}$.
Hollow circle	$\frac{\pi (R^4 - R_1^4)}{4}$.
Flanged girder, omitting strains in the web	$\frac{A A_1 D^2}{A + A_1}$.
Flanged girder, including strains in the web	$\left(A + \frac{A_2}{3}\right) d^2 + \left(A_1 + \frac{A_3}{4}\right) d_1^2$.
Flanged girder, including strain in the web, with equal flanges	$\frac{(6 A + A_2) D^2}{12}$.
Solid elliptic beam	$\frac{\pi E E_1^3}{4}$.
Hollow elliptic beam	$\frac{\pi (E E_1^3 - E_2 E_3^3)}{4}$.

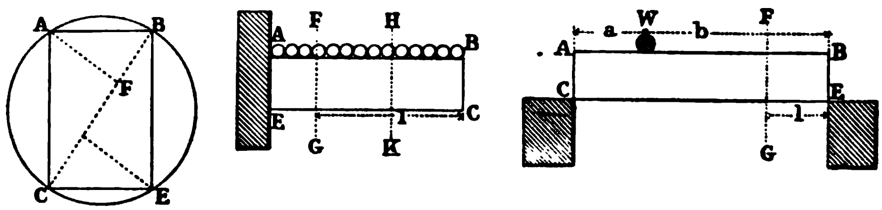
5387.



In Table IV. the letters have the following values;—B = breadth of beam, or side of the square; D = depth of beam; A = area of top flange, A_1 = that of bottom, A_2 = area of part of web above the neutral axis, and A_3 that of the part below it; E = horizontal semi-axis, E_1 vertical semi-axis. Having obtained the value of the total moment of resistance of a beam, or the moment of the interior forces, we have now to find that of the exterior forces, and by equating the two, we can arrive at an expression for the breaking weight for each particular form of beam. In Fig. 5387, let A B C E be a solid beam, fixed at one end A E, and unsupported at the other, at which there is a weight W suspended. It is required to find what must be the value of W to break the beam at the line F G. Evidently the force tending to break the beam is equal to the weight multiplied by the leverage, equal to $W \times l$. The force resisting this tendency is the moment of the interior forces $= M = \frac{F \times I}{x}$. As these two forces make equilibrium at the line F G, the equation is $W \times l = \frac{F \times I}{x}$. Taking F to represent the ultimate strain on the unit of area, and to have its maximum value, which it has when $x = \frac{D}{2}$, the equation can be put in a more useful form. Referring to Table IV. for the value of I, for this kind of beam, we have $I = \frac{B D^3}{12}$. Substituting this value, and putting $x = \frac{D}{2}$, we get $W = \frac{F \times B D^2}{6 l}$. As an example. What weight situated at the end of a beam of teak 10 ft. in length, similar to that in Fig. 5387, and 12 in. deep and 4 in. broad, will break it across? From the equation $W = \frac{12050 \times 4 \times 12 \times 12}{6 \times 10 \times 12} = 9640$ lbs. In order therefore to calculate the breaking weight of any solid beam of any particular form in the position in Fig. 5387, the general formula is $W = \frac{F \times I}{l \times x}$, and by substituting the values of I and x, the calculation for each can be made. From this equation is derived the rule for determining the strongest beam that can be cut out of a round log of timber. Let A B C E, in Fig. 5388, be a round log, out of which it is required to cut the beam inscribed, of maximum strength. These conditions are fulfilled when $B D^2$ is a maximum, and also in the diagram, when $C B^2 = B^2 + D^2$ = also a maximum. Differentiating, we obtain from the first of these $\frac{dB}{dD} = -\frac{2B}{D}$, and from the second $\frac{dB}{dD} = -\frac{D}{B}$, whence

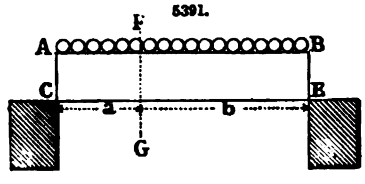
$B = \frac{D}{1 \cdot 41}$. Geometrically, this may be done as follows;—Draw any diameter C B, make $BF = \frac{BC}{3}$, and draw F A perpendicular to B C, to meet the circumference in A. Join A B and A C, and complete the parallelogram.

5388. 5389. 5390.



The next case to consider is that of a similar solid girder loaded uniformly, as shown in Fig. 5389. What is the breaking weight at any point F G? It is evident that the weights situated between the line F G, and the fixed end of the beam, have no tendency to fracture it at that line. Also, the sum of the weights situated between the line F G, and the free end of the girder, may be considered to act at their centre of gravity, that is at a distance equal to $\frac{l}{2}$. Let W = the sum of these weights, then $\frac{W l}{2}$ is the force tending to break the beam at F G. Equating this as before, with the value of M, we have $\frac{W l}{2} = \frac{F \times B D^3}{12 x}$, from which $W = \frac{F \times B D^2}{3 l}$. Since the strength of a beam is directly as the quantity $B D^2$, and inversely as the value of l, a beam of uniform strength need not be also of uniform area, as will be seen hereafter. The next general case is that in which a solid beam is supported at both ends, and loaded at any point, as in Fig. 5390. Put W for the weight which would break the beam at any point F G, L for the span of the beam between supports, a and b for the segments into which W divides the beam, and l for the distance of F G from the support, which is the farther from W. On the principles of the lever, the force tending to break the beam at F G is the reaction of the support at E, multiplied by the leverage, or the distance l, which is equal to $\frac{W \times a \times l}{L}$. Putting this equal to M, and since $M = \frac{F \times I}{x}$, we have $\frac{W \times a \times l}{L} = \frac{F \times I}{x} = \frac{F \times B D^2 \times L}{6 a l}$. If the weight be at the centre, the breaking weight at that point will be, $W = \frac{2 F B D^2}{3 L}$; for in that case $a = l = \frac{L}{2}$. The same calculation can be made for any other form of beam, by substituting the proper values of I in the general equation $M = \frac{F \times I}{x}$. The last case to be considered is that of a solid beam similarly situated as the last, but loaded uniformly over its whole length, as in Fig. 5391. Put L for the span of the girder, W for the total load, and a and b for the segments into which the line F G, where the breaking strain is required, divides the beam. The forces tending to fracture the beam, are the reaction of the support at A, multiplied by the leverage, minus the weight of the part of the load situated between F G and A, also multiplied by the leverage. The reaction $= \frac{W}{2} = \frac{w L}{2}$ when w = load per foot run of the beam, and the leverage $= a$. The other force equals $w a \times \frac{a}{2} = \frac{w a^2}{2}$, so that the equation is $\frac{w L a}{2} - \frac{w a^2}{2} = \frac{w a (L - a)}{2}$. But $L - a = b$ and $w = \frac{W}{L}$, so the equation becomes $\frac{W \times a \times b}{2 L}$. Putting this equal to M, we have

5391.



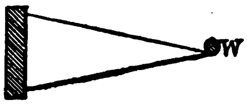
$$\frac{W \times a \times b}{2 L} = M = \frac{F \times I}{x} = \frac{F \times B D^3}{12 \times x}.$$

Solving, we obtain $W = \frac{F \times B D^2 L}{3 a b}$. If the breaking weight be at the centre, $W = \frac{4 F B D^2}{3 L}$, since $a = b = \frac{L}{2}$. Accordingly as we vary the breadth or depth of beams of uniform strength, so will their section vary.

The effect of varying these dimensions, upon the plan and elevation of beams of uniform strength, is shown in Figs. 5392 to 5403. The depth is supposed to be constant in Figs. 5392 to

5397, and the breadth in Figs. 5398 to 5403. The former series of figures will consequently represent the plan and the latter the elevation of the different beams, which are as follows;—Figs. 5392, 5398, a solid beam fixed at one end and loaded at the other. Figs. 5393, 5399, a solid beam or flanged girder, fixed at one end and loaded uniformly. Figs. 5394, 5400, a solid beam supported

5392.



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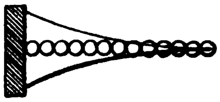

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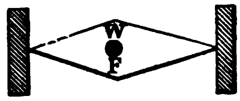
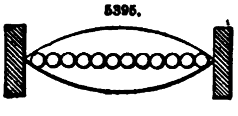


5395.



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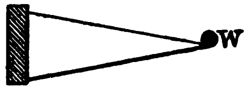

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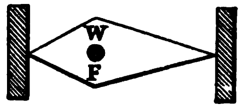

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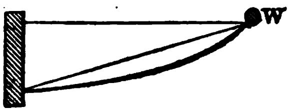
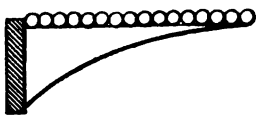
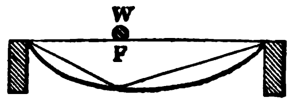


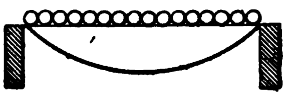
5399.



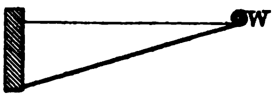
5400.



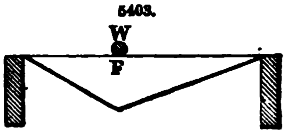
5401.



5402.

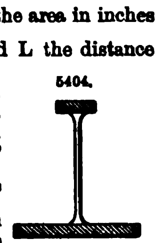


5403.



at both ends and loaded at any point F. Figs. 5395, 5401, a solid beam or flanged girder supported at both ends and loaded uniformly. Figs. 5396, 5402, a flanged girder fixed at one end and loaded at the other. Figs. 5397, 5403, a flanged girder supported at both ends and loaded at any point F. When the depth is constant, the plan will vary, and when the breadth is constant, the elevation. If the strength of a beam, fixed at one end and loaded at the other, be represented by unity, that of a similar beam, loaded uniformly, will be represented by 2; that of a similar beam, supported at both ends, and loaded at the centre, by 4; and that of a similar beam, supported at both ends, and loaded uniformly, by 8. A more convenient, and more practical method of calculating the strength of solid rectangular beams, is by using a constant, derived from actual experiment on beams exposed to transverse strain. Let C = this constant. Put W for the breaking weight in lbs., A for the area of the beam, D for its depth, and L for the span, all in inches. Then for the four class of beams we have been considering, taking them in the same order, we have $W = \frac{A \times D \times C}{L}$; $W = \frac{2A \times D \times C}{L}$; $W = \frac{4A \times D \times C}{L}$; $W = \frac{8A \times D \times C}{L}$. The constant C, which is termed the modulus or coefficient of rupture, is determined by actually breaking a beam of given dimensions of the given material, and of a similar form to that, the strength of which is required. The values of C for various materials are given in Table V., and they are the breaking weights of solid beams fixed at one end and loaded at the other, whose breadth, depth, and length are each equal to 1 in. The general formula for the breaking weight at the centre of any solid beam or flanged girder is, $W = \frac{A \times D \times C}{L}$, in which A is the area in inches of the solid beam, or the area of the bottom flange of the girder, D the depth, and L the distance between the supports in inches, W the breaking weight in tons, and C a constant, also in tons, derived from experiment upon a similar solid beam or flanged girder. The value of C for cast-iron beams of the best form, as shown in Fig. 5404, is 26 tons. *Example.*—What is the breaking weight of a cast-iron girder 20 ft. in span, 18 in. in depth, and having the lower flange 15 in. broad by $1\frac{1}{2}$ in. thick? By the formula $W = \frac{22 \cdot 5 \times 1 \cdot 5 \times 26}{20} = 43 \cdot 87$ tons. The area of the bottom flange is to that of the top as 6·5 to 1. In the application of this formula to the beam in Fig. 5404, the value of the vertical part of the beam or web is not taken into consideration. Another formula in which its value is included is $W = \frac{2(d^3 - (b - b_1)d_1^3)}{3 \times D \times L}$, in which W = breaking weight in tons, L = span in feet, and the other dimensions in inches, b = breadth of bottom flange, d = whole depth, b_1 = thickness of web, and d_1 = depth to the inside of the bottom flange. The former has the advantage of simplicity, and is that usually employed. Instead of the breaking weight, the practical problem to be frequently solved, is to find the actual strain upon a girder at any given point, resulting from a weight or weights placed at other points. To take the simplest case, let A B C E in Fig. 5387 be a flanged girder, fixed at one end, and loaded at

5404.



any point H K with a weight W_1. Let L = total length of girder, D the depth, and x the distance of the weight W_1 from the line F G, where the strain is required. The force tending to produce rupture at F G is the weight multiplied by the leverage, which equals $W \times x$. The force tending to resist rupture is the strain in either top or bottom flange multiplied by the leverage, which equals $S \times D$. Equating, $W_1 \times x = S \times D$, and $S = \frac{W_1 \times x}{D}$. If the weight be situated at the end of the girder, $x = l$, and $S = \frac{W_1 \times l}{D}$. If the line H K be situated at A E, the leverage is a maximum, and the strain also, which is $S = \frac{W_1 \times L}{D}$. This horizontal strain S is equal in each flange, is tensile in the upper, and compressive in the lower. To find the strain at any point, when the girder is uniformly loaded with a weight W, we proceed as follows;—In Fig. 5389, let A B C E be the girder uniformly loaded. It is required to find the strain at any point F G. The forces on the one side are the sum of the units of weight situated between the line F G, and the free end of the girder, multiplied by the leverage, which is equal to half this distance, equal to $\frac{l}{2}$, and that on the other, as in the former example. Putting w for the unit of weight and equating moments as before, we have $\frac{w \times l^2}{2} = S\,D$, and $S = \frac{w \times l^2}{2\,D}$. When the line F G coincides with A E, $w \times l = W$, and $l = L$, and $S = \frac{W \times L}{2\,D}$

TABLE V.—MODULI OF RUPTURE IN LBS. A SQUARE INCH.

Acacia	1,867	Kakarall, Demerara	2,379
Ash, American	1,795	Larch, American	911
" " swamp	1,165	" English	1,335
" " black	861	Lignum vitæ	2,013
" English	2,026	Locust, Demerara	3,430
Beech, American white	1,380	Mahogany, Nassau	1,719
" " red	1,739	Mangrove, Bermuda black	1,699
" English	1,556	" " white	1,985
Birch, American black	2,061	Maple, soft Canada	1,694
" " yellow	1,335	Norway spar	1,474
" English	1,928	Oak, Adriatic	1,471
Box, Australian	2,445	" African	2,523
Bullet-tree, Demerara	2,692	" American live	1,862
Cabacally	2,518	" " red	1,687
Canada balsam	1,123	" " white	1,743
Cedar, Bermuda	1,443	" Dantzic	1,518
" American white	766	" English	1,694
" Guadaloupe	2,044	" Italian	1,688
Crab, Demerara	1,875	" Lorraine	1,483
Deal, Christiana	1,562	" Memel	1,665
Elm, Canada	1,970	Pine, American red	1,527
" English	782	" " pitch	1,727
Fir, Mar forest	1,232	" " white	1,229
" spruce	1,346	" " yellow	1,185
" American black	1,036	" Archangel	1,370
Greenheart, Demerara	2,615	" Dantzic	1,426
Hemlock	1,142	" Memel	1,348
Hickory, American	2,129	" Prussian	1,445
" bitter nut	1,465	" Riga	1,383
Iron bark, Australia	2,288	" Virginia	1,456
" cast, small bars	7,616	Poon	1,954
" " large "	5,040	Sneeze-wood, South Africa	3,305
" " small round bars	4,480	Spotted gum, Australia	2,006
" wood, Canada	1,800	Stringy bark, Australia	1,818
" wrought, new bars	8,557	Teak	2,108
" " bent and straightened	12,500	Walaba	1,643
" " new round	5,040	Yellow-wood, West Indies	2,103

The behaviour of Greenheart, when subjected to a crushing pressure, differs so much from that of other woods under similar conditions, that it deserves to be noticed. The Demerara, or English Guiana Greenheart, is the *Laurus chloroxylon* of botanists, and is also found in Jamaica and the Brazils. It is distinguished as the black and the yellow. The kind usually imported into England is of a deep brownish-yellow colour, with a very close grain and fine polish, and full of extremely minute cells. The concentric rings are scarcely visible, and there is a considerable portion of sap-wood. Greenheart is very hard and flexible, and when loaded to the crushing point behaves as follows;—It supports for a long time the addition of successive weights without evincing any signs of yielding or weakness. But no sooner has the weight reached a certain amount, and become equal to the ultimate strength of the material, than the wood gives way at once with a loud sharp report, and without showing the least premonitory symptom of the coming fracture. After the fracture, the piece presents the appearance of a mass of fibres, without either form or arrangement. The

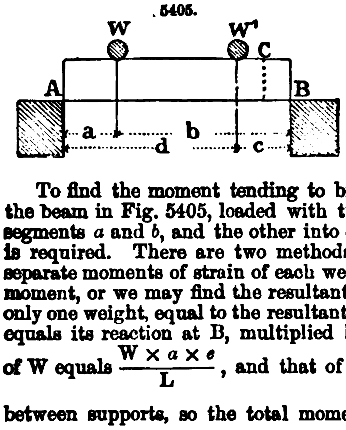
conclusion to be drawn is that up to a certain point, that is, to very near the crushing weight, Greenheart possesses great tenacity, but becomes suddenly endowed, when that limit is reached, with a brittleness of corresponding magnitude.

The next case is represented in Fig. 5390, in which A B C E is a girder supported at each end, and loaded with a weight W. What is the strain at any point F G? The forces are S × D, and the reaction of the right support, multiplied by the leverage, which gives $S \times D = \frac{W \times a \times l}{L}$; from which $S = \frac{W \times a \times l}{D \times L}$. The maximum strain occurs when W is at the centre, that is, when $a = l = \frac{L}{2}$, and the equation becomes $S = \frac{W \times L}{4 \times D}$

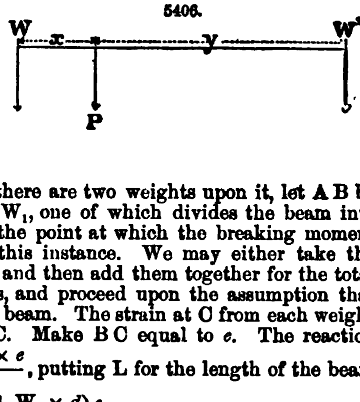
Example.—What is the strain at the centre of a girder having a span of 100 ft. and a depth of 10 ft., resulting from a weight of 20 tons placed at the centre? Here we have $W = 20$, $L = 100$, and $D = 10$; therefore $S = \frac{20 \times 100}{4 \times 10} = 50$ tons.

When the girder is uniformly loaded, the strain at any point may be found as follows;—In Fig. 5391, let the girder be similarly placed as in the last example, and loaded uniformly, and let the strain be required at the point F G, dividing the girder into segments a and b. The force acting on one side of this line is the reaction at the left abutment, multiplied by the leverage or length of the segment a, and that on the other is the strain S, multiplied by its leverage, and the weight of the segment a, multiplied by its leverage, which is equal to $\frac{a}{2}$, since it may be considered to act at its centre of gravity. Equating these, we have, putting W_1 for the weight of the segment $\frac{W \times a}{2} = S \times D + \frac{P \times a}{2}$; from which $S = \frac{a}{2}\left\{\frac{W - P}{D}\right\}$. But $P = \frac{W \times a}{a + b}$; consequently $S = \frac{a}{2 \times D}\left\{\frac{W(a+b) - Wa}{a+b}\right. = \frac{W \times ab}{2DL}$. The limits of the value of a and b are $a = o$, $b = L$, and $a = b = \frac{L}{2}$. In the former instance, $S = o$, and in the latter, $S = \frac{W \times L}{8 \times D}$. If the different equations relating to these beams and girders be compared, it will be found that a girder fixed at one end and loaded at the other, will only bear half the weight that it will if it be uniformly loaded. Similarly, a girder supported at both ends and loaded at the centre, will only bear half the weight that it will when uniformly loaded. The strains on the flanges are in the same relative proportion.

5405.



5406.



To find the moment tending to break a beam when there are two weights upon it, let A B be the beam in Fig. 5405, loaded with two weights W and W_1, one of which divides the beam into segments a and b, and the other into c and d. Let C be the point at which the breaking moment is required. There are two methods of proceeding in this instance. We may either take the separate moments of strain of each weight at the point C, and then add them together for the total moment, or we may find the resultant of the two weights, and proceed upon the assumption that only one weight, equal to the resultant, is placed upon the beam. The strain at C from each weight equals its reaction at B, multiplied by the distance B C. Make B C equal to e. The reaction of W equals $\frac{W \times a \times e}{L}$, and that of W_1 equals $\frac{W_1 \times d \times e}{L}$, putting L for the length of the beam between supports, so the total moment at $C = \frac{(W \times a + W_1 \times d)\,e}{L}$. Making R and R_1 = respectively the reaction of W and W_1, we have for the value of the moment, $M = (R + R_1)\,e$. To use the other method, the position of the resultant must be first found. In Fig. 5406, let it be at P, and supposing the weights to be unequal, let it divide the distance between the weights into unequal segments x and y. The proportion is $x : y :: W_1 : W$, or putting l for the distance between the weights, $x : l - x \because W_1 : W$; and $x = \frac{W_1 \times l}{(W + W_1)}$, which determines the position of the resultant. Make the resultant equal P, then the moment of strain at C equals $\frac{(P \times e)\,(x + a)}{L}$. But $P = W + W_1$ and $x = \frac{W_1 \times l}{W + W_1}$, so that the moment of strain at C equals

$$\frac{(W + W_1)\,e}{L}\left(\frac{W_1 \times l}{W + W_1} + a\right).$$

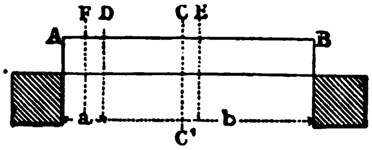
Example.—Let the girder be 100 ft. in span, one of the weights equal to 5 tons and the other equal to 10 tons, placed 10 ft. respectively from each end of the girder. What is the moment

of strain at a point 5 ft. from that end of the girder nearest the heavier weight? By the first method, we have $M = \frac{(W a + W_1 d) e}{L} = \frac{(5 \times 10 + 10 \times 90) 5}{100} = 47 \cdot 5$ tons. By the second, $M = \frac{(W + W_1) e}{L} \times \left(\frac{W_1 \times l}{W + W_1} + a\right) = \frac{(5 + 10) 5}{100} \times \left(\frac{10 \times 80}{15} + 10\right) = \frac{15}{20} \times \frac{190}{3} = 47 \cdot 497$ tons, or the same result as by the former method.

A remarkable instance of a beam being loaded with a couple of weights, occurred in the cross-heads of the presses employed to raise the tubular girders of the Britannia Bridge. The method of finding the moment of strain at any point O in Fig. 5405, by using the resultant of the two weights, will not answer when the point is situated between the weights, whether that point be at the centre or elsewhere. If the two weights are situated upon different sides of the point of strain, they cannot be represented by a single resultant, since the reaction of both abutments must be taken into consideration.

In Fig. 5407, let the moment of strain at the point D be required on the beam A B, uniformly loaded with a load W the foot run. The reaction of the weights to the right of D equals $\frac{W \times b^2}{2 L}$, and the moment of strain at D equals $\frac{W \times b^2 \times a}{2 L}$. Similarly the moment of strain of the sum of the weights to the left of D equals $\frac{W \times a^2 \times b}{2 L}$, so that M, the total moment, is given by the

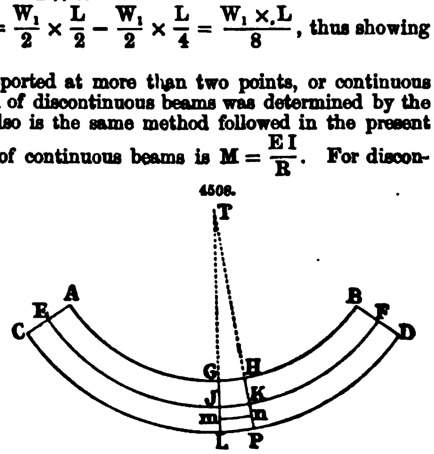
5407.



equation $M = \frac{W (a b^2 + a^2 b)}{2 L} = \frac{W a b (a + b)}{2 L}$. Making W_1 = the total load, and remarking that $(a + b) = L$, and $W_1 = W \times L$, we have $M = \frac{W_1 \times a \times b}{2 L}$. There is another method of arriving at the strain upon the point D, which is shorter and simpler than that just described. Since the load is uniformly distributed over the whole beam, the reaction at each abutment is equal to half the total load, and the strain at the point D is equal to the reaction of the half load at the support A, minus the moment of the weights situated between A and D, which acts at the centre of gravity. Using the same notation, we have $M = \frac{W \times L \times a}{2} - \frac{W \times a^2}{2} = \frac{W \times a}{2} (L - a)$. But $(L - a) = b$, and $W = \frac{W_1}{L}$, so that we obtain as before, $M = \frac{W_1 \times a \times b}{2 \times L}$. For the moment at the centre, $a = b = \frac{L}{2}$, and $M = \frac{W_1 \times L}{8}$. Or, as before, $M = \frac{W_1}{2} \times \frac{L}{2} - \frac{W_1}{2} \times \frac{L}{4} = \frac{W_1 \times L}{8}$, thus showing the accuracy of each method.

Continuous Beams.—The strength of beams supported at more than two points, or continuous beams, next claims our attention. As the strength of discontinuous beams was determined by the equating of the external and internal forces, so also is the same method followed in the present instance. The general equation for the strength of continuous beams is $M = \frac{E I}{R}$. For discontinuous beams, $M = \frac{F \times I}{x}$; so that $\frac{F}{x} = \frac{E}{R}$. In Fig. 5408, let A B C D represent part of a beam, of which the neutral line is E F, and let it be supposed to be bent in a curve, of which the centre is at T. Draw T P and T L, perpendicular to the neutral line, and dividing the beam into two transverse sections exceedingly close to one another. If we consider J K to be the neutral fibre, it will represent the length of all the fibres in the beam, before it was bent, since it is the only fibre unalterable in length. Put this length equal to l, and l_1 for the difference of length in any other fibre $m n$, after the deflection of the beam. The total length of the fibre $m n$ will now be equal to $(l + l_1)$. If P be the force which extended the fibre $m n$ to a length of $(l + l_1)$, E the modulus of elasticity, and a the sectional area of the fibre, which is supposed to be very small, then $P = \frac{E \times a \times l_1}{l}$. Make the radius of curvature equal to R, and K n equal to d, and by similar triangles, we have T n : $n m$ :: T K : K J, or $(R + d) : n m :: R : K J$. But $n m = (l + l_1)$ and $K J = l$, so $(R + d) : (l + l_1) :: R : l$. From this $\frac{R + d}{R} = \frac{l + l_1}{l}$, and $1 + \frac{d}{R} = 1 + \frac{l_1}{l}$, or $\frac{d}{R} = \frac{l_1}{l}$. Substituting this value of $\frac{l_1}{l}$ in the former equation, we obtain $P = \frac{E \times a \times d}{R}$. The moment of this force is equal to $P \times d = \frac{E \times a \times d^2}{R}$. But the integral of $a d^2$, as was found in deducing the transverse strength of beams, is equal to I; therefore, calling M the moment of all the elastic forces, we have $M = \frac{E \times I}{R}$.

4508.

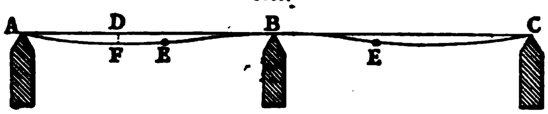


To put this equation in a form adapted for calculation, the value of R is found by the differential

calculus to be equal to $-\frac{1}{\frac{d\,x^2}{d^2\,y}}$, on the assumption that the deflection is small in comparison with the length of the curve, which is concave to the axis x. Substituting this value for R, in the equation for M, we have $M = -E \times I \frac{d^2 y}{d x^2}$. This is the equation which we shall use in determining the strength of continuous beams, and the deflection of beams generally.

Let A B C, in Fig. 5409, be a continuous beam of two spans. The conditions are that the beam is of uniform section, that the spans are equal, that it is supported by the reaction of the three points A B and C, and that it is uniformly loaded with a weight w over every lineal foot of span. Put L for the length of each span, P for the reaction of the support A, P_1 for that of B, and P_2 for that of C. Let $A\,D = x$, and $D\,F = y$ = the deflection at that point, and E_1 and E, the points of contrary flexure, or those points in which the curve changes signs.

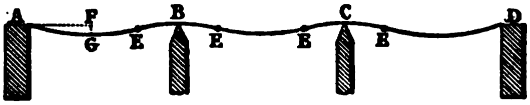
5409.



As before explained, the problem is to find the moments of the external and internal forces upon the beam, and equate them. The latter of these, or the elastic forces, called into play is equal to M, and it remains to determine the former. The part of the beam A F is equilibrated by the reaction of the support A, and the weight uniformly distributed over it, which therefore acts at its centre of gravity. The leverage, with which these forces act, is equal respectively to x and $\frac{x}{2}$, and their moments are $P \times x$ and $\frac{w \times x^2}{2}$. We thus obtain $M = P \times x - \frac{w \times x^2}{2}$, and substituting for M, its value in terms of the moment of inertia of the section, we have $E\,I \frac{d^2 y}{d x^2} = \frac{w\,x^2}{2} - P \times x$. Integrating, this becomes $E\,I \frac{d y}{d x} = \frac{w\,x^3}{6} - \frac{P \times x^2}{2} \times C$. The value of the constant C is determined from the conditions, that at the centre support B, the tangent to the curve is horizontal, and x is equal to L. Therefore $E\,I \frac{d y}{d x} = \frac{w \times x^3}{6} - \frac{P \times x^2}{2} + \frac{P \times L^2}{2} - \frac{w \times L^3}{6}$. Another integration will give $E\,I \times y = \frac{w \times x^4}{24} - \frac{P \times x^3}{6} + \frac{P \times L^2 \times x}{2} - \frac{w \times L^3 \times x}{6}$. But it will be seen from Fig. 5409, that when $x = L$, $y = o$, so that the equation becomes $\frac{w \times L^4}{24} - \frac{w \times L^4}{6} = \frac{P \times L^3}{6} - \frac{P \times L^3}{2}$, from which $P = \frac{3 \times w \times L}{8}$. But $P_2 = P$ and $P_2 + P_1 + P = 2\,w \times L$, from which $P_1 = \frac{5\,w \times L}{4}$. To find the point in the beam between A and E, at which the maximum strain occurs, that is the value of x, we have $P - w\,x = o$, and $x = \frac{P}{w}$. But $P = \frac{3\,w \times L}{8}$, so $x = \frac{3\,L}{8}$. For the position of the points of contrary flexure, it must be borne in mind that the sum of the elastic forces equals zero, or $M = o$. Therefore to find x we have $P = \frac{w \times x}{2}$. Substituting the value already obtained for P, we obtain $x = \frac{3\,L}{4}$, or, in Fig. 5409, $A\,E = 3\,B\,E$.

The case of a continuous beam of three spans is shown in Fig. 5410, supported at the four points A, B, C, D, and the same conditions with respect to uniformity of section, equality of span, and rate of loading, are assumed as in the previous example. Put P for the reaction of each of the supports A and D, and P_1 for B and C, and let x and y represent as before the co-ordinates of the deflection curve at any point F G.

5410.



From the equation of moments, we have $E\,I \frac{d^2 y}{d x^2} = \frac{w \times x^2}{2} - P \times x$, and by integration, $E\,I \frac{d y}{d x} = \frac{w \times x^3}{6} - \frac{P \times x^2}{2} + C$. In this instance of three spans, the tangent to the curve is not horizontal at the point B, and $\frac{d y}{d x} = \tan.\ \theta$, when $L = x$. A second integration gives $E\,I\,y = \frac{w \times x^4}{24} - \frac{P \times x^3}{6} + x\left(E\,I \tan.\ \theta - \frac{w \times L^3}{6} + \frac{P \times L^2}{2}\right)$. At the point B, $x = L$, and $y = o$, so we obtain $E\,I \tan.\ \theta = L^2\left(\frac{w \times L}{8} - \frac{P}{8}\right)$. The quantity P still remains to be found, and the simplest method of proceeding is to determine another value for the left-hand side of the equation, and then to reduce and eliminate the value of the separate reactions. Let x and y equal the co-ordinates of the deflection curve at any point of the beam, then equating the forces, we

have $E\,I\frac{d^2 y}{d x^2} = \frac{w \times x^2}{2} - P \times x - P_1(x - L)$. When $x = L$, $\frac{dy}{dx} = \tan.\theta$, and integrating again, $E\,I\frac{dy}{dx} = \frac{w(x^3 - L^3)}{6} - \frac{P(x^2 - L^2)}{2} - \frac{P_1(x - L)^2}{2} + E\,I\tan.\theta$. At the middle point of the centre span, the deflection curve is horizontal, and $\frac{dy}{dx} = o$, whence

$$E\,I\tan.\theta = \frac{x - L}{2}\big(P(x + L) + P_1(x - L)\big) - \frac{w(x^3 - L^3)}{6}$$

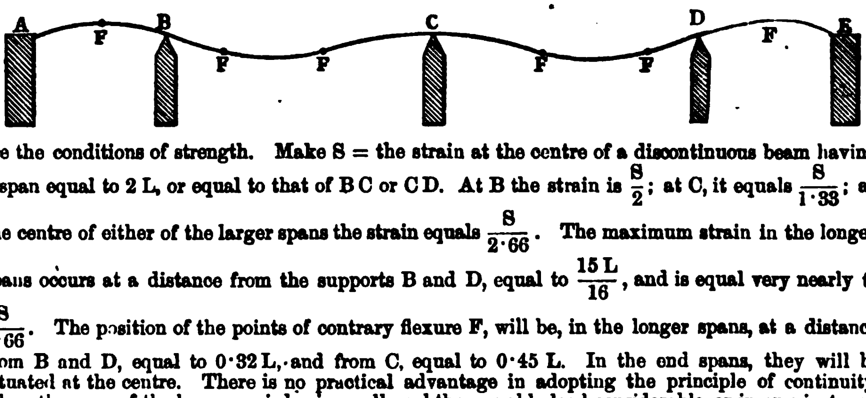
At this point in the centre span, $x = \frac{3L}{2}$, and substituting, $E\,I\tan. \quad = L^2\left\{\frac{5P + P_1}{8} - \frac{19\,w\,L}{48}\right\}$

But the total reaction of the supports equals $2P + 2P_1 = 3\,w\,L$, from which $P_1 = \frac{3\,w\,L - 2P}{2}$. We can now proceed to find P. From the two equations for the value of $E\,I\tan.\theta$, we have $\left(\frac{5P + P_1}{8} - \frac{19\,w\,L}{48}\right) = \left(\frac{w\,L}{8} - \frac{P}{3}\right)$. Substituting and reducing, $P = \frac{2\,w\,L}{5}$, and $P_1 = \frac{11\,w\,L}{10}$. Putting in the equation $E\,I\tan.\theta = L^2\left(\frac{w\,L}{8} - \frac{P}{3}\right)$, the value for P, we get $E\,I\tan.\theta = -\frac{w\,L^3}{120}$

The principle of analysis is the same for a continuous beam of any number of spans, but the complete investigation of the subject is not suited to our pages.

There are several practical points worth attention with respect to continuous beams. In the example shown in Fig. 5409, the greatest strain in each of the side spans is to the strain in the centre span as 9 : 16. The strain in the centre span is equal to that at the centre of a discontinuous beam having an equal span. In Fig. 5410, let S represent the strain at the centre of a discontinuous beam whose span equals L, then the maximum strain in the end spans of the continuous beam equals $\frac{S}{1 \cdot 565}$ at a distance from the end of $\frac{2L}{5}$. The strain over the middle supports equals $0 \cdot 8\,S$, and that at the centre of the middle span equals $\frac{S}{5}$. The position of the points of contrary flexure E from the supports B and C will be in the centre span equal to $0 \cdot 275\,L$, and in the end spans $0 \cdot 20\,L$. If a continuous beam be supported at five points A B C D E, as in Fig. 5411, which represents the length of the centre span as double that of the end ones, the following

5411.



are the conditions of strength. Make S = the strain at the centre of a discontinuous beam having a span equal to 2 L, or equal to that of B C or C D. At B the strain is $\frac{S}{2}$; at C, it equals $\frac{S}{1 \cdot 33}$; at the centre of either of the larger spans the strain equals $\frac{S}{2 \cdot 66}$. The maximum strain in the longer spans occurs at a distance from the supports B and D, equal to $\frac{15\,L}{16}$, and is equal very nearly to $\frac{S}{2 \cdot 66}$. The position of the points of contrary flexure F, will be, in the longer spans, at a distance from B and D, equal to $0 \cdot 32\,L$, and from C, equal to $0 \cdot 45\,L$. In the end spans, they will be situated at the centre. There is no practical advantage in adopting the principle of continuity, when the span of the beam or girder is small, and the movable load considerable, or in any instance, whatever may be the proportion of span and load, in which the foundations are not of a perfectly stable character. When the load is of a static nature, and moreover constant, there is a manifest economy in adopting it, and also whenever the permanent weight of the girder is considerably in excess of the movable load, as happens in railway bridges of large span. When the movable load is much in excess of the weight of the structure itself, the continual shifting of the position of the points of contrary flexure is attended with many practical disadvantages.

Deflection of Beams.—The deflection of beams of any form, and under any conditions, can be readily deduced from the moments of the internal and external forces, the values of which have been already investigated. We shall determine the deflection of one example in order to show the method to be employed, but the results only of others will be given in Table VI. The case consists of a beam supported at both ends, and loaded uniformly, throughout its whole length. Let L = span of beam, w = unit of load, or load for each lineal foot of span; W = total load = $w \times L$. Put x and y for the co-ordinates of the deflection curve. Make E I = K. Then moment of elastic forces $= -K\frac{d^2 y}{d x^2}$; and moment of external forces $= \frac{w\,L \times x}{2} - \frac{w \times x^2}{2}$. Equating these, we have $K\frac{d^2 y}{d x^2} = \frac{w\,x^2}{2} - \frac{w\,L\,x}{2}$. Integrating, $K\frac{dy}{dx} = \frac{w\,x^3}{6} - \frac{w\,L\,x^2}{4} + C$. At the centre, where the deflection is a maximum, $\frac{dy}{dx} = o$, and $x = \frac{L}{2}$, so $C = \frac{w\,L^3}{16} - \frac{w\,L^3}{48}$, and $K\frac{dy}{dx} = \frac{w}{2}\left(\frac{x^3}{3} - \frac{L\,x^2}{2} + \frac{L^3}{12}\right)$.

Another integration gives $K\,y = \frac{w}{24}(x^4 - 2\,L\,x^3 + L^3\,x)$. When the deflection is a maximum, that is at the centre of the beam $y = D$, putting D for the deflection, and $x = \frac{L}{2}$. By substitution, therefore, we get $D = \frac{w\,L^4}{24\,K}\left(\frac{1}{16} - \frac{1}{4} + \frac{1}{2}\right)$, whence $D = \frac{5\,w\,L^4}{384\,K}$. But $w\,L = W$, and $D = \frac{5\,W\,L^3}{384\,E\,I}$.

In finding the actual value of the deflection of any beam, the quantity I must be replaced by its value given in Table IV. This has been done in Table VI., which therefore gives the deflection of beams and girders of different sections, in terms suitable for direct numerical calculation. There are four principal cases of deflection of beams;—1. Beam fixed at one end and loaded at the other. 2. Beam fixed at one end and loaded uniformly. 3. Beam supported at both ends and loaded at the centre. 4. Beam supported at both ends and loaded uniformly. The deflections in the last three instances may be easily obtained from that of the first, without repeating the whole process of integration and reduction. Let D = the deflection of a solid beam fixed at one end and loaded at the other, and $D_1\,D_2\,D_3$ the deflections in the three remaining instances. Then we have the following relations;— $D_1 = \frac{3\,D}{8}$; $D_2 = \frac{D_1}{6} = \frac{D}{16}$; $D_3 = \frac{5\,D_2}{48} = \frac{5\,D_1}{288} = \frac{5\,D}{768}$. The spans, and rate of loading, are supposed to be constant in all the beams. If the deflection of case 1 be calculated by the formula, $K\frac{d^2\,y}{d\,x^2} = -\,W\,(L - x)$ by the rules already laid down, that of the others is obtained by simply multiplying by the proper factor. It is to be noticed, that in continuous beams, the depth exercises no influence upon the position of the points of contrary flexure, or points of inflection, as they are sometimes termed.

TABLE VI.—DEFLECTION OF BEAMS AND GIRDERS.

Description.	Value of D.
Solid rectangular cantilevers loaded at the end	$\frac{4\,W\,L^3}{E\,B\,D^3}$.
Solid round cantilevers	$\frac{4\,W\,L^3}{3\,E\,\pi\,R^4}$.
Hollow ditto ditto	$\frac{4\,W\,L^3}{3\,E\,\pi\,(R^4 - R_1^{\,4})}$.
Horizontal flanged cantilevers neglecting the web	$\frac{W\,A\,L^3}{3\,E\,a\,a_1\,D^2}$.
Ditto taking the web into account	$\frac{4\,W\,L^3}{E\,(6\,a + a_1)\,D^2}$
Square tubes of uniform thickness	$\frac{4\,W\,L^3}{E\,(B^4 - B_1^{\,4})}$.
Ditto in which the thickness is small compared with B	$\frac{W\,L^3}{2\,E\,B^3\,T}$.
Solid rectangular cantilevers loaded uniformly ..	$\frac{3\,W\,L^3}{2\,E\,B\,D^3}$.
Solid round cantilevers	$\frac{W\,L^3}{2\,E\,\pi\,R^4}$.
Hollow ditto ditto	$\frac{W\,L^3}{2\,E\,\pi\,(R^4 - R_1^{\,4})}$.
Horizontal flanged cantilevers neglecting the web	$\frac{W\,A\,L^3}{8\,E\,a\,a_1\,D^2}$.
Ditto taking the web into account	$\frac{3\,W\,L^3}{2\,E\,(6\,a + a_1)\,D^2}$.
Square tubes of uniform thickness	$\frac{3\,W\,L^3}{2\,E\,(B^4 - B_1^{\,4})}$.
Ditto in which the thickness is small compared with B	$\frac{3\,W\,L^3}{16\,E\,B^3\,T}$.
Solid rectangular beams on two supports, and loaded at the centre	$\frac{W\,L^3}{4\,E\,B\,D^3}$.
Solid round beams	$\frac{W\,L^3}{12\,E\,\pi\,R^4}$.
Hollow round beams of uniform thickness	$\frac{W\,L^3}{48\,E\,\pi\,R^3\,T}$.
Horizontal flanged beams neglecting the web ..	$\frac{W\,A\,L^3}{48\,E\,a\,a_1\,D^2}$.

TABLE VI.—DEFLECTION OF BEAMS AND GIRDERS—*continued.*

Description.	Value of D.
Horizontal flanged beams taking the web into account	$\frac{W L^3}{4 E (6 a + a_2) D^2}$.
Solid rectangular beam on two supports, loaded uniformly	$\frac{5 W L^3}{32 E B D^3}$.
Solid round beam	$\frac{5 W L^3}{96 E \pi R^4}$.
Hollow round beam of uniform thickness	$\frac{5 W L^3}{384 E \pi R^3 T}$.
Horizontal flanged beams not taking the web into account	$\frac{5 A W L^3}{384 E a a_1 D^2}$.
Ditto taking the web into account, and with flanges of equal area	$\frac{5 W L^3}{32 E (6 a + a_2) D^2}$.

In Table VI. the letters signify the same quantities used in determining the strains on beams. $A = a + a_1$ = the sum of the areas of the upper and lower flanges, and a_2 = the area of the web. In the flanged beams the value of D is not that of the total depth of the beam, but only of the web; that is, it is measured from inside to inside of the flanges instead of from outside to outside.

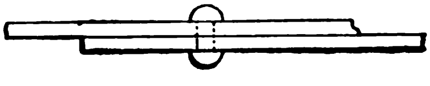
Shearing Strain.—A shearing strain is one which tends to cause the particles of the body to separate by slipping or sliding upon one another. Referring to Fig. 5387, the weight W tends to cause the immediate part of the beam upon which it rests to separate vertically, or shear from the adjoining part, and this tendency is transferred, from point to point, to the fixed extremity of the beam at A E. The shearing strain upon that part of the beam, situated between the weight and the fixed end, is constant for every section of the beam. Calling it S, then $S = W$. The exact manner in which this strain is propagated throughout the web of a flanged girder is not known, but it has been ascertained that the directions vary, being sometimes diagonal as well as vertical. The probability is that the strain is frequently propagated in curved lines also. If a flanged girder is fixed at one end, and uniformly loaded, the shearing strain at any point, is equal to the sum of the units of weights situated between the point and the end of the girder. If the girder is supported at both ends, and loaded with a weight at any point, the shearing strain, at any point, is equal to the portion of the weight transmitted, on the principle of the lever, to the abutment situated on the opposite side of the point to that at which the weight is placed. If a girder is supported at both ends, and loaded uniformly, the shearing strain at any point is equal to the sum of the units of weight placed between it and the centre of the girder. In solid beams of considerable length, exposed to a transverse strain, failure occurs by the fibres being compressed or extended in a horizontal direction, and the shearing strain, which acts in a vertical direction, is neglected. If we now suppose the beam to become very short, the horizontal strains are proportionally diminished, and at last give place altogether to that of a shearing character. The tendency is no longer to pull the short beam asunder, or to double it up, but to cut it in two.

As the formulæ we have investigated for the strength of beams do not include failure under these conditions, the action of a shearing strain must be considered separately. In using a pair of shears or common scissors, the pin which holds the blades together, is exposed to this strain, so also is the rivet which fixes the blade of a pocket-knife to the handle. With an equal force, and equal area of rivet, the shearing strain in the latter case is double that in the former, as will be easily seen. If the blades of the shears are pulled asunder, they will shear the pin in the middle. One section only will be made, each half of the pin attaching itself to each blade of the shears. But if the blade of the knife be torn away from the handle, it will carry with it the middle part of the rivet, and leave the two ends in each half of the handle. Two sections are made in this instance. In the one case the rivet is said to be in single, and in the other in double shear. The leverage in beams, so short as to be broken by a shearing strain, is practically equal to zero, so that the moment of the force equals the force itself. The strength of any body, or the resistance therefore that it exerts against a shearing strain, is directly proportional to the area of the section exposed to the strain. If T be the ultimate shearing strength of any body, F the force required to shear it across, and A its area in inches, then $F = A \times T$. It is not necessary to give a table of the values of T for different materials, as they may be considered, for all practical purposes, to be equal to those given in Table II. for the ultimate tensile strengths. Experiment has established this approximate identity. Care must be taken, in making use of this formula, that the whole of the sectional area is exposed, at one and the same time, to the action of the shearing strain. This is always ensured in engineering structures, but machines are frequently constructed to act differently. Shearing machines are made so as to exert their force in detail, and in this respect differ from punching machines, which cut the whole piece out at the first operation. Numerous experiments afford the following average shearing strain for wrought iron. Punching plate iron 24·6 tons; punching hammered scrap-iron 20·9 tons; shearing hammered scrap-bars and rolled iron 22·1 tons. The mean result of the experiments, made during the erection of the Britannia and Conway tubular bridges, gave 23·3 tons a square inch as the shearing strain of rivet iron of good quality. As the ultimate tensile strength of the same iron was found to be 24 tons, the resistance to a tensile and shearing strain may be regarded as practically identical. This identity is not universal. If the tensile strength of steel is represented by unity, its shearing strength equals 0·738 ton for each square inch of section. Experience has also proved that it requires a third more pressure to shear wrought iron than copper. Fir will shear in the direction of the grain with less than one-twentieth

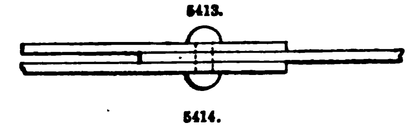
of the force that will tear it asunder. With respect to the shearing strength of oak treenails, it is to be observed that the thickness of the planks through which they pass influences the amount—the thicker the plank the greater the strength. About 2 tons to the square inch is the average force required to shear treenails of English oak.

In Figs. 5412, 5413, 5414, a rivet is shown in single, double, and treble shear, and the strength of each joint is in corresponding proportion. If C is the ultimate shearing strength of the material, N the number of the plates through which a pin or rivet passes, A its sectional area in inches, then, calling the shearing strain of the rivet S, we have $S = A\,C\,(N - 1)$. Large holes, that is, large sections of iron, are sheared with less force than punched, and although it appears somewhat paradoxical, thin plates require a proportionally greater force to punch them than thick ones. The form of the blade of the shearing machine has considerable influence upon the force required, especially in relation to the position of the bar to be sheared, which is not a matter of indifference. Suppose a bar, 3 in. in breadth and ½ in. in thickness, in which position will it shear the most readily, edgeways or on the flat? If the shearing blades be parallel, the bar will shear with equal facility in either position. If they be inclined, the bar placed on the flat will shear with four-fifths of the force which is required if it be placed on the edge. When the bar is on its edge, the force required with parallel blades is to that with inclined as 110 to 100, and when on the flat as 125 to 100.

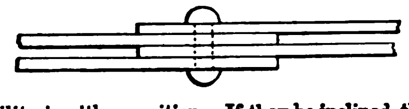
5412.



5413.



5414.

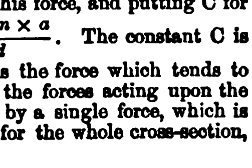


That the resistance to shearing is proportional to the area of the cross-section of the body, is proved mathematically as follows;—Let d be the original distance between two cross-sections of a prismatic body, extremely close to one another, and let one of these sections be supposed to be fixed, and the other to slide in a vertical plane, relatively to the other. This sliding motion will be constant for all the points in the cross-section, and may be represented by m. Any small particle of the sliding section, which put equal to a, will, in consequence of the elastic power of the material, tend to return to its original position in the plane of section. The force it will develop in so doing is proportional to a, and also proportional to the relative sliding motion, and the original distance between the two vertical planes of section. Make F equal to this force, and putting C for a constant varying with the nature of the material, we have $F = \frac{C \times m \times a}{d}$. The constant C is the coefficient of shearing, and has been already referred to. As F is the force which tends to prevent the sliding of a particle a in the plane of section, and as all the forces acting upon the whole cross-section are parallel to each other, they may be represented by a single force, which is their resultant. Calling this force R, and assuming C to be constant for the whole cross-section,

$$R = \frac{C \times m}{d} \int a.$$

A common instance of a shearing strain, or, as it is sometimes called, a strain of detrusion, is shown in Fig. 5415, in which A B is the end of the tie-beam of a roof, and C the foot of the rafter let into it. The thrust of the rafter may be resolved into two directions, one vertical, and the other horizontal. The former is equilibrated by the vertical reaction of the abutment, and the latter by the resistance of the end of the tie-beam. The tendency is evidently to shear, or slice off, the piece of the tie-beam between the foot of the rafter and A, having a breadth equal to that of the tie-beam, and a depth equal to that of the distance which the rafter penetrates. Making B equal breadth of beam, T the horizontal thrust of the rafter, and D the distance from the foot of the rafter to the end of the tie-beam, then, when the material is oak, $D = \frac{T}{575\,B}$, and, when fir, $D = \frac{T}{150\,B}$. In practice the strain is provided for, either by connecting the rafter and tie-beam with a strap or with a bolt.

5415.

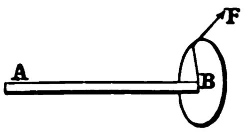


Strain of Torsion.—The last strain to be considered, with reference to our subject, is that of torsion, which has considerable influence, as will be seen, on the strength and shape of the axles of railway carriages and locomotives. The strength of a prismatic body to resist a strain of torsion, will depend partly upon its moment of inertia, and partly upon the value of a constant, to be determined for each material. If we consider two cross-sections of the body, which is supposed to be homogeneous, to be very close to each other, the moment of the exterior torsional forces will tend to cause one of these sections to rotate relatively to the other, about their common axis. Let one of these sections be regarded as fixed, then any point in the other will be twisted through a certain angle. If d be the distance of the point from the axis of the prism, and θ the circular measure of the angle of torsion, the angular displacement of the particle will be equal to $d\,\theta$. If D be the distance between the original cross-sections, the displacement of the whole fibre, of which the particle under consideration may be regarded as the extreme end, relatively to D is equal to $\frac{d\,\theta}{D}$. Experiment has proved that the resistance of a fibre to torsion is proportional to its area, and to $\frac{d\,\theta}{D}$. Put A for the

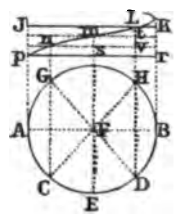
area of the fibre, C for the value of the constant, and R for the resistance of the fibre, then $R = \frac{C \times A \times d\,\theta}{D}$, and the moment of this resistance equals $R \times d$. Make this equal M, then $M = \frac{C \times A \times d^2 \theta}{D}$, and the sum of all the moments in the whole cross-section will equal $\frac{C \times \theta}{D} \int a\, d^2$. But from Table IV., in which is given the strength of beams of various forms, the expression $\int a\, d^2$, which is known as the moment of polar inertia, is the moment of inertia of a cross-section of a homogeneous prism about an axis, passing through its centre of gravity, and perpendicular to its plane. Designating it by its proper symbol I, we have $M = \frac{C \times \theta \times I}{D}$. Calling M_1 the moment of the exterior forces tending to produce torsion, we have $M_1 = M = \frac{C \times \theta \times I}{D}$. This is the general equation of equilibrium for the exterior forces, and the resistance to torsion for each cross-section of a homogeneous prism.

A more important case, in at least a practical point of view, to investigate, is that of a cylindrical beam or rod, under a strain of torsion. Let A B, in Fig. 5416, represent a cylindrical beam which is acted upon by a force F, which tends to twist it round its axis. If we suppose all the cross-sections of the shaft, from one end to the other, to be fixed, it is evident that the torsional strain must be transmitted throughout them successively, and each one will only be subjected to the strain after the next one, nearest the end of the beam at which the force is applied, has been caused to rotate. Before the extremity A can move, the whole length of the shaft must be undergoing strain. In Fig. 5417, let a cylinder under a torsional strain be represented in projection on the two planes A G H B D E C, J p r K, which are perpendicular to one another. If the particle D at one end of the cylinder begins to move, it will arrive at a certain point A before the particle L, at the other extremity, has moved at all. Suppose that L begins to move when D arrives at A; then the line D L, or the generating line of the cylinder, has been twisted into the thread of a screw. Let D E C A and L m n p be the projections of the thread on the two planes respectively. Similarly the particles D t and D v have taken up the positions represented by C n and E s, and the sections p r, n v, m L, have been turned through the angles of torsion D F A, D F C, and D F E. If θ be the angle of torsion for the whole cylinder, and L the length of the cylinder, we have for the moment of the exterior forces $M = \frac{C \times \theta\, I}{L}$,

5416.



5417.



or, by transposition, $\theta = \frac{L \times M}{C \times I}$. Taking C and I as constant for the same material, and same cross-sections of shaft, the angle of torsion is directly proportional to the force of torsion, and the length of the shaft or rod. Putting R for the radius of the cylinder, the value of I is $\frac{\pi R^4}{2}$, so that the equation may be written $M = \frac{C \times \theta \times \pi R^4}{2 L}$ for solid cylinders, and for hollow, $M = \frac{C \times \theta \times \pi}{2 L} (R^4 - R_1^4)$, in which R and R are the external and internal radii. The following are the values of C for different materials in tons to the square inch.

TABLE VII.

Material.	Value of C in tons.	Material.	Value of C in tons.
Wrought iron	3810	Bronze	700
Iron in bars	4232	Copper	2800
German steel	3810	Fir	275
Cast iron	1270	Oak	254
Cast steel	6350		

As a practical example of the force of torsion, the following experiment was carried out. A cylindrical rod of forged iron 9·2 ft. in length, and 0·57 in. in diameter, was subjected to a strain of torsion, produced by a weight of 22·5 lbs., acting at the end of a lever 13 in. in length. Before the rod broke, it was twisted through an angle of torsion equal to 13 4 degrees. A cast-iron cylindrical bar, having a length of 4·92 ft., and a diameter of 4 in., was acted upon by a weight of 3690 lbs. at the end of a lever 6·56 ft. in length, and was twisted through an angle of torsion of 15 degrees. When the weight was increased to 4680 lbs., the angle increased to 20·25 degrees, and the bar broke at last with a weight of 4905 lbs. This experiment bears out the statement that the angle of torsion is proportional to the force of torsion, since 15 × 4905 equals 20·25 × 3690 sufficiently closely to corroborate the theory. When considerable masses are put in

motion, the effect of torsion is often observable to the eye, more especially when the motion is transmitted and multiplied from one piece of machinery to another. A prime mover can frequently be observed in motion, before some more distant part of the machine is set going. From numerous experiments on torsion, the weight which will twist asunder a cylindrical bar of wrought iron of good quality, 1 in. in diameter, acting at the end of a lever 1 ft. in length, is 1000 lbs. For wrought iron of ordinary quality, this weight should not be taken greater than 800 lbs. For cast iron of good quality it may be taken to be 700 lbs. It should be remarked here that if the torsional force applied, exceeds the limit of elasticity of the material, a permanent twist will be the result. This might be inferred, from what has been already stated respecting the permanent set of materials under a strain of tension. If S be the strength of a standard bar, having a diameter of 1 in., and S_1 that of any other bar having a diameter equal to D, we have $S_1 = S \times D^3$, and if P be the resistance of any bar, W the weight, and R the radius of the lever at the end of which it acts, then $P = \frac{W}{R}$. In Table VIII. the relative strength of several materials to resist torsion is given, wrought iron being taken equal to unity. In many instances the stiffness of shafts and bars under torsion, is of more importance than their absolute strength. The torsional stiffness of shafts varies as $\frac{D^4}{L}$, in which D is the diameter, and L the length. In practice, the diameter of long shafts is always in excess of that which is absolutely required to resist torsion. If it were not so, it would be impossible to get the machinery to work smoothly and steadily.

TABLE VIII.

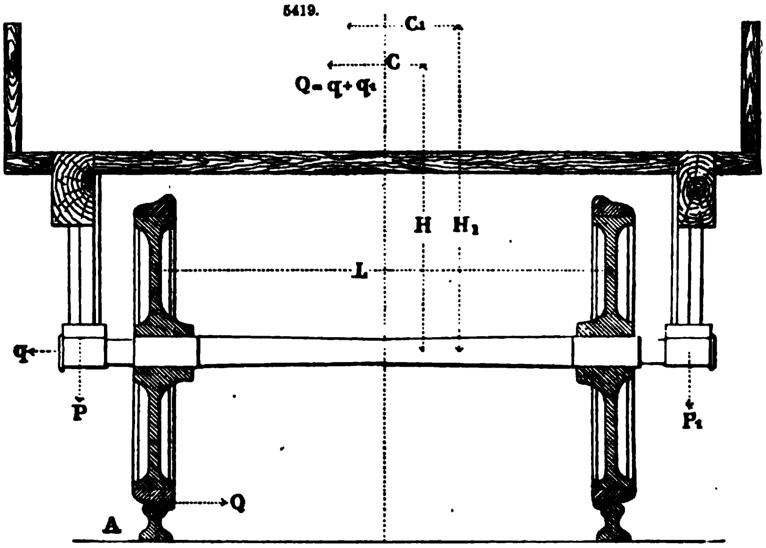
Wrought iron	1·00	Copper	0·43
Brass	0·46	Gun-metal	0·50
Cast iron	0·90	Lead	0·10
Cast steel	1·95	Tin	0·14

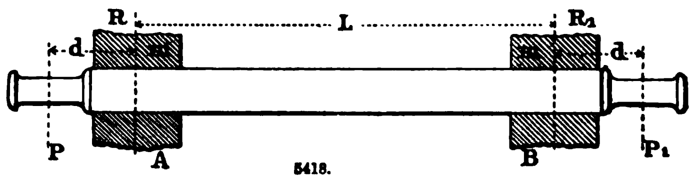
Railway Axles.—The most prominent example in practice of the effect of torsion is to be found in the case of railway axles. An accident which occurred recently on one of the English railways, demonstrated the startling fact that the proper form of axles was not known to the company. We shall first investigate the question of the strength of axles, and then refer to the accident, and point out the improved form which has since been adopted. Whenever the vertical pressures acting upon the journals of an axle are equal, and the corresponding reactions of the rails, all the cross-sections between the wheels undergo a uniform strain, if the weight of the axle itself is neglected. If P be the pressure upon the journal, and L the distance between the centre of the wheel-bed and a vertical plane, passing through the centre of the rail, then the moment of the force equals P × L. It follows from this, that if the axle were always subjected to a uniform load, each cross-section would undergo the same strain, and the correct shape of the axle would be cylindrical. But experience has proved that axles never break in the middle, but always either at the journals or just behind the wheel-bed. At these points, therefore, the strain is evidently greater than at others, and the conclusion to be arrived at is, that the cross-section of the axle may be reduced beyond these points. It can be readily shown mathematically, that so long as the pressures upon an axle are vertical, the true form is the cylindrical. In Fig. 5418 let A and B be the cross-sections through the nave of a pair of wheels, showing the axle lying in its bearings. Let P and P_1 equal the pressure upon the journals, R and R_1 the corresponding reaction of the rails, L the distance from the centre of one rail to that of the other, d the distance from the centre of the journals to the vertical plane, passing through the centre of the rail-head, and m the distance from this plane to the inside edge of the wheel-bed. Neglecting the weight of the axle itself, and considering the rails as the points of support, the equations of equilibrium are $R \times L = P(L + d) - P_1 \times d$, and $R_1 \times L = P_1(L + d) - P \times d$, from which $R = P + \frac{d}{L}(P - P_1)$ and $R_1 = P_1 - \frac{d}{L}(P - P_1)$. Putting M for the moment of flexure for the section of the axle nearest the inner edge of the wheel-bed, we have $M = P_1(d + m) - R_1 \times m$. Substituting for R_1 its value already found, we get $M = P_1 \times d + (P - P_1)\frac{m \times d}{L}$. Similarly, the moment M_1 of the section behind the wheel-bed is $M_1 = P(d + m) - R \times m$, and substituting for R its value, we have $M_1 = P \times d - (P - P_1)\frac{m \times d}{L}$. If M_2 be the moment of flexure at the centre of the axle, $M_2 = P\left(\frac{L}{2} + d\right) - R\frac{L}{2}$, and substituting for R its value, the equation becomes $M_2 = \left(\frac{P + P_1}{2}\right) \times d$. If $P = P_1$, then $M_2 = M_1 = M P \times d$, and there is no reason for making any one cross-section of the axle different from the other.

Let us now take another condition in which an axle is constantly placed. Suppose that in Fig. 5419 the flange of one of the wheels A grinds the rail. Immediately a pressure is created upon the wheel, which acts horizontally and parallel to the axle, and tends to throw the carriage towards the centre of the track. Call this pressure Q. But at the same time, the weight of the carriage tends to restore it to its original position, with a force acting in the opposite direction, the point of application of which is situated at the centre of gravity of the whole wagon and load bearing upon the axle. Call this force Q_1, and let it act at the point C, placed at a height H above the centre of the axle. The force Q is composed of two others $q + q_1$, the former of which acts at a point C_1, at a height of H_1 above the centre of the axle, and the latter

at the centre of the axle itself. The forces q and q_1 are to one another as the pressures P and P_1. The force q acting at the point C_1 is transmitted to the axle by the frame and springs of the

5419.





5418.

carriage, so that the axle has to support not only the normal load $P + P_1$, but also the reaction due to the force q, which tends to push the carriage outward. Let this reaction be supposed to act upon the journal in the wheel A, and put it equal to r. It will be understood that at the journal in the opposite wheel B, the value of r, instead of being added, will be subtracted from the load. Using the same notation as before, we have, in order to find the two forces, $P + r$ and $P - r$, which act along the whole length of the axle, $r\,(L + 2\,d) = q \times H_1$, when $r = \dfrac{q \times H_1}{L + 2\,d}$. The pressure at A will be $P + \dfrac{q \times H_1}{L + 2\,d}$, and at B, $P - \dfrac{q \times H_1}{L + 2\,d}$. In order to determine the reactions R and R_1 of the rails which are transmitted to the axles by the wheels, it must be observed that, in addition to the vertical pressures P and P_1 upon the journals, there are a couple of horizontal forces Q Q to be taken into account. Putting y for the radius of the wheel, the moment of each of these forces is $Q \times y$. But there exists at the centre of gravity C, a horizontal force $Q = q + q_1$, the moment of which is $y + H$, so that we have $Q\,(y + H) = Q\,y + q\,H_1$. The action of this couple increases the pressure upon the wheel A, and diminishes it on B, by a certain quantity, which put equal to t. To find t we have $t \times L = Q\,(y + H) = Q\,y + q\,H_1$; whence $t = \dfrac{Q\,y + q\,H_1}{L}$, and the reactions R and R_1 are given by the equations $R = P + t = P + \dfrac{Q\,y + q\,H_1}{L}$ and

$$R_1 = P - t = P - \frac{Q\,y + q\,H_1}{L}.$$

There are thus six forces acting upon the axle, the two vertical pressures P and P_1 acting downwards, the two reactions R and R_1 acting upwards, and the horizontal forces, the moment of which is $Q \times y$. Under the action of these six forces, which together make equilibrium, the axle has to resist not merely a bending strain, but a strain of torsion as well, which acts throughout its whole length, the mathematical axis of which does not pass through the centre of gravity at all the cross-sections. The bending moments for the three principal points in the axle may be thus found. For the cross-section just behind the wheel-bed of B,

$$M = P_1\,(d + m) - R_1\,m = (P - r)\,d + (t - r)\,m.$$

For the section at the middle,

$$M_1 = P_1\left(d + \frac{L}{2}\right) - R_1\,\frac{L}{2} = (P - r)\,d + (t - r)\,\frac{L}{2}.$$

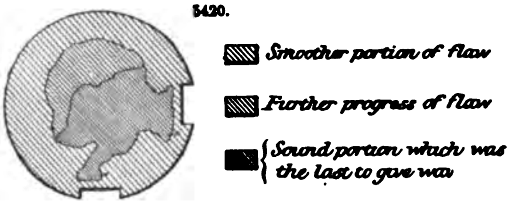
For the section behind the wheel-bed at A,

$$M_2 = P_1(d + L - m) - R_1(L - m) = (P - r)d + (t + r)(L - m).$$

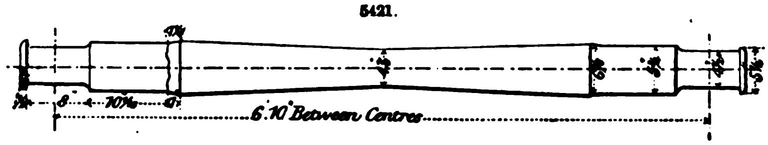
This last moment is therefore the greatest, and the moment of the middle section is the mean between the other two, increased by the quantity $\frac{Q\,y}{2}$, in order to take into account the horizontal force. We thus see that the bending moment and the total strain are greatest at the section just behind the wheel-bed, which is known as the dangerous section. It must be concluded, therefore, that the cylindrical form is not the correct form to adopt, in order to produce an axle of uniform strength. The correct form may be thus arrived at;—Divide the distance extending from the middle of the axle, to the vertical plane passing through the centre of the rail-head, into five parts. Make D = the diameter of the middle part of the axle at 0, $D_1 = 1\cdot0417$ D at 1, $D_2 = 1\cdot0804$ D at 2, $D_3 = 1\cdot1162$ D at 3, $D_4 = 1\cdot1501$ D at 4, and $D_5 = 1\cdot1821$ D at 5.

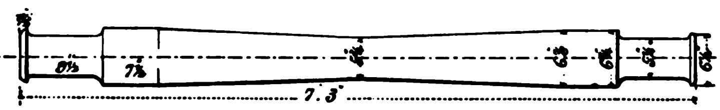
The accident which led to the adoption of the correct form of axle by the North-Eastern Railway Company occurred in September of 1872, and formed, as is the rule in such cases, the subject of an inquiry by the Board of Trade. The history of the accident, as well as the conclusions drawn, therefore, are full of interest, and have an intimate bearing upon our subject. The elevation and sections of the broken axle are shown in Figs. 5420, 5421, and the form subsequently adopted by the company is represented in Fig. 5422.

5420.



5421.





5422.

As the second express train leaving London at 10.10 A.M., and Newcastle at 5 15 P.M., for Edinburgh, was passing between the above two stations, the trailing axle of the tender of No. 250 engine suddenly gave way. The leading van and a first-class carriage were, in the first instance, and three third-class carriages were afterwards, thrown off the rails.

The train in question consisted of an engine and tender, seven passenger carriages, a mail-van, and two brake-vans.

After stopping at Morpeth, Bilton, and Belford, and leaving one of the carriages at Morpeth, the engine-driver proceeded forward. He ran through the Beal Station at a speed from 40 to 45 miles an hour, and he kept up about the same speed until, in passing a point a mile and a half north of Beal, and 8 miles north of Belford, he felt his engine run very uneasily. He shut off his steam, and looked round, and saw fire flying from the back of the tender. His fireman applied the tender-brake, and he applied the brake which was attached to his engine; but not tightly, because he was afraid of pulling up too suddenly. He ran on, reducing his speed at first to about 15 or 20 miles an hour, and then pulling up at about 600 yds. from the point at which his tender first left the rails. He was going on pretty steadily, when the wheels dropped from under the tender, the tender reared up, and the brake-van became uncoupled. The engine and tender then went on by themselves for about 50 yds. before they were brought to a stand, and the carriages came to a stand about 10 or 15 yds. behind the tender. On examination it was then found that the engine was on the line with all its wheels, and the tender with its leading and middle wheels; but the axle of the trailing wheels having been broken, one wheel of the tender lay under the carriages, while the other wheel, with a portion of the axle still in it, lay under the tender. As regards the van and carriages, the van No. 50, East Coast rolling stock, was off the rails with two of its wheels, an East Coast carriage, No. 7, was off the rails with its leading wheels, a third-class carriage, No. 60, was off its four wheels, a third-class carriage, No. 40, was off with two wheels, and the tender-wheel, above referred to, lay under the tender.

The other vehicles of the train, consisting of the mail-van, two carriages, and the rear van, remained on the line. There was a hole knocked in the bottom of the tender by a blow from the loose wheel, and some damage done to the carriages by the bending of the axles; but in other respects the carriages were not much damaged. The dimensions of the axle which thus gave way are shown in Fig. 5421. It measured 6 ft. 10 in. long between the centres of the journals, 4⅝ in. in diameter in the middle, 6¼ in. in diameter outside of the wheel-bed, 5¾ in. in diameter inside of the wheel-bed. It was found to have given way, as shown in the diagram, at 1¼ in. inside of the wheel-bed.

The fracture occurred, as in most of these cases, at the point where the diameter changes. The flaw had been produced gradually by the constant action, for a series of years, during the running of the tender. Having been inside of the wheel-bed it was not visible to outward examination, and the fracture would not be discovered until the wheel was separated from the axle. The axle was again broken at the shops of the company at Gateshead, and found to be of excellent quality. It bent very considerably before fracture could be obtained, and it was found necessary then to nick it before it could be broken. The engine, No. 250, was an express engine, with the driving and trailing wheels coupled together. These wheels were 6 ft. 6 in. in diameter, and the leading wheels were 4 ft. 6 in. in diameter. The weight on the leading wheels was 9 tons, the trailing wheels 10 tons 10 cwt., and on the driving wheels 14 tons 10 cwt., making a total of 34 tons with the engine in working order. The diameter of the cylinders was 16 in., with a stroke of 24 in. The wheel-base measured 7 ft. 10½ in. from leading to driving, and 8 ft. from driving to trailing wheels.

The tender-wheels were 3 ft. 6 in. in diameter, and the wheel-base measured from leading to middle wheels 6 ft., and middle to trailing wheels also 6 ft. The tank was constructed to hold 2000 gallons of water. The weights on the tender were as follows;—Leading wheels 8 tons, middle wheels 8 tons 10 cwt., trailing wheels 7 tons 15 cwt.; total, 24 tons 5 cwt. The total mileage run by this tender, and also by this axle, was 150,918 miles, from January, 1868, until 13th September, 1872.

On further examination after the accident, similar flaws were detected in the other axles of this tender, both of which were taken out and condemned as unfit for further use.

The remedy by which accidents of this nature may be prevented is perfectly simple. It is by so constructing the axles, with enlarged dimensions at the wheel-beds and at the journals, and smaller dimensions proportionately towards the middle, in order that when fractures occur, which must be the case occasionally, this fracture may be visible to outward observation, instead of occurring in the wheel-beds, in places where they cannot be seen. Fig. 5422 shows the alterations the company have made, in order to carry out these conditions in all axles which they construct in future. Another point necessary to be attended to is the selection of good material, and the tight and proper fitting of the wheels upon the axles.

For the want of tightness in this particular instance, and in most other cases, the flaws have occurred principally opposite the beds of the keys, by which the wheel was kept in its place upon the axle. If the wheel and axle had been so fixed together as to be practically one whilst running, the fracture under notice would probably have occurred, even in this case, and with this form of axle, outside of the wheel, and therefore open to observation.

On the portion of line where this accident occurred the gradient was rising 1 in 240.

We cannot conclude this portion of our subject, without drawing attention to the great advantage possessed by cast steel in all instances of construction, in which a strain of torsion is to be resisted. This material is especially adapted for the manufacture of railway axles, since it will withstand a bending and a breaking strain of double the amount which wrought iron can sustain. The relative diameters of two axles, one of cast steel and the other of wrought iron, will be $\sqrt[3]{1} : \sqrt[3]{2}$, or nearly as 4 : 5, and the relative weights as 0·63 : 1. The loads being equal, an axle of cast steel will have only five-eighths of the weight of one of wrought iron, and yet do the same work. Another advantage resulting from the employment of cast steel in axles, is that the journals may be made a great deal smaller. The diameter of the journal of a cast-steel axle is to that of one of wrought iron as 0·707 : 1. This reduction in the diameter is partly owing to the fact, that under a given pressure, steel journals heat less rapidly than those of wrought iron. Moreover, the smaller the diameter of the journals, compared with that of the wheels, the easier the haulage. It will be manifest from our remarks on the shearing strain of materials, that the edges of the wheel-beds are very much exposed to a strain of that character. In practice this liability is very much mitigated by rounding off the edges of the wheel bearings, so as to bring the pressure nearer the centre of the bearing surface. The testing of the strength of axles is frequently accomplished by the hydraulic press. An example tested at Berlin was submitted to a pressure of 410 atmospheres, when the body of the press gave way, and the trial was left unfinished.

Working Load.—The actual load which is placed, in practice, upon any single beam or compound structure is considerably less than that which would break it. The proportion which this load, or working load as it is technically called, should bear to the ultimate strength of the material, has long been an undecided question. Engineers are still far from unanimous on the point. The extreme limits have been put at 3 and 10. The proportion, moreover, depends not only upon the absolute breaking strength of the material, but also upon the particular conditions under which the body is placed. Manifestly, a beam which would safely carry 10 tons placed gradually and gently upon the centre, would not bear the same load let fall upon it, from a height of 10 or 12 ft. The proportion which the safe working load, or the load applied in practice to any material, bears to the ultimate strength of the material, is called the fraction of safety. The values of this fraction are given in Table IX. for different materials under different specified conditions, in fractional parts of the ultimate or breaking strength. In applying these values of the fraction of safety, care must be taken to employ the ultimate strength corresponding to the strain to which the material is subjected. The nature of the strain which the material undergoes must be first ascertained, and then the proper fraction of safety applied to the calculation. The factor of safety is the inverse of the values given in Table IX. Thus the factor of safety for a pillar of wrought iron not subject to vibration is 4. The rule of the Board of Trade allows for railway girders, a working tensile strain of 1·25 ton to the square inch, and a compressive strain of 6·0 tons on the same unit for good cast iron. The structure is supposed to be secured from deflection. The rule is as follows;—In a cast-iron bridge, the breaking weight of the girders shall not be less than three times the permanent load, due to the weight of the superstructure, plus six times the greatest moving load that can be brought upon it. In practice, engineers modify this rule a little, and design cast-iron girders to bear a breaking weight of six times the total load, or six times the

permanent load, plus six times the greatest moving load. For wrought-iron railway bridges, the rule of the Board of Trade is:—In a wrought-iron bridge, the greatest load which can be brought upon it, plus the weight of the superstructure, shall not produce a greater strain upon any part of the material than 5 tons to the square inch. This is tantamount to assuming that one-fourth of the breaking strain for wrought-iron girders subject to vibration is the safe working strain, and this is the proportion adopted by English engineers. The French rule is that the safe working strain shall not exceed 3·81 tons to the square inch, which would make the ratio as 5·25 to 1. In Table IX. the values given for steel are derived from very imperfect data, our experience with regard to the use of that material as a constructive agent being still very limited. For the safe working load on timber piles, driven into the ground, experience has shown that 1000 lbs. to the square inch of the head of the pile may be allowed, and about one-fifth of this amount for piles driven into soft ground, and having comparatively but little hold.

TABLE IX.—VALUES OF THE FRACTIONS OF SAFETY FOR DIFFERENT MATERIALS.

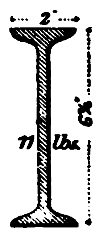
How Situated.	Fraction.
Cast Iron.	
Pillar not subject to vibration or impact	$\frac{1}{6}$
„ subject „ „	$\frac{1}{10}$
Beam or girder subject to vibration and impact, such as a railway-bridge girder	$\frac{1}{6}$
Beam or girder not subject to vibration	$\frac{1}{4}$
„ „ subject to sudden shocks as in cranes and machinery	$\frac{1}{8}$
Wrought Iron.	
Pillar not subject to vibration	$\frac{1}{4}$
„ subject „	$\frac{1}{6}$
„ subject to direct and sudden shocks	$\frac{1}{10}$
Boiler-work	$\frac{1}{8}$
Chains	$\frac{1}{6}$
Wire rope, round	$\frac{1}{7}$
„ flat	$\frac{1}{6}$
Beam or girder subject to vibration ..	$\frac{1}{4}$
Beam or girder not subject to vibration	$\frac{1}{3}$
„ „ subject to sudden and violent shocks	$\frac{1}{6}$
Steel.	
Plates under a tensile strain	$\frac{1}{3}$
Pillars not subject to any flexure ..	$\frac{1}{4}$
Timber.	
Posts and pillars	$\frac{1}{10}$
„ used for temporary works	$\frac{1}{4}$
Piles when fixed in the earth	$\frac{1}{10}$
In bridges and permanent structures ..	$\frac{1}{10}$
Brickwork, stone, concrete, and rubble masonry	$\frac{1}{8}$
Ashlar and cut stone in pillars and ring-pens	$\frac{1}{20}$
Common mortar	$\frac{1}{10}$
Cordage	$\frac{1}{4}$

Rolled Iron Beams.—There are two classes of beams which remain to be mentioned, namely, the wrought-iron rolled beam and the flitch or composite beam. The former is shown in Figs. 5423 to 5433, and consists of an upper and lower flange of equal sectional area and a vertical rib. The

5423.

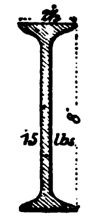
Span.	Distributed Safe Load.
feet.	tons.
6	2·0
8	1·7
10	1·4
12	1·2
14	1·0
16	0·9

5424.



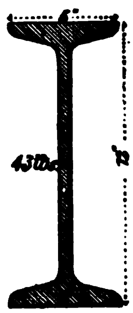
8	3·6
10	3·3
12	2·9
14	2·4
16	2·0
18	1·7

5425.



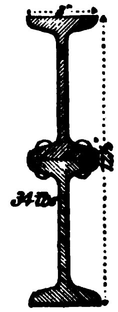
8	6·8
10	5·7
12	4·8
14	4·0
16	3·4
18	3·1
20	2·8
22	2·5

5426.



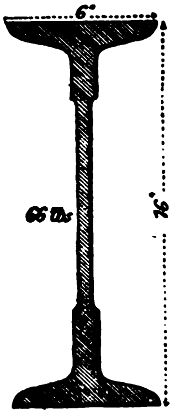
Span.	Distributed Safe Load.
feet.	tons.
10	22·0
12	19·1
14	16·0
16	13·2
18	12·1
20	11·0
22	9·0
24	8·2
26	7·3

5427.



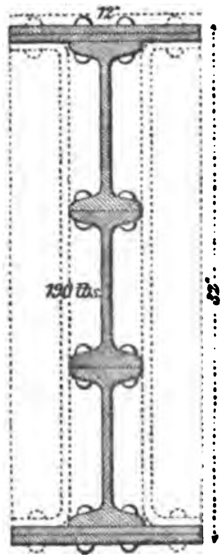
10	18·0
12	15·0
14	13·0
16	11·0
18	9·0
20	8·0
22	7·0
24	6·0
26	5·0

5428.



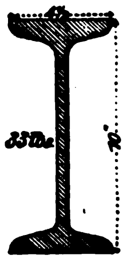
Span.	Distributed Safe Load.
feet.	tons.
10	40·0
12	35·0
14	30·0
16	26·0
18	23·0
20	20·0
22	18·5
24	17·0
26	15 0

5429.



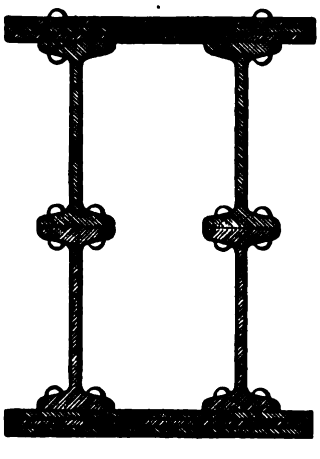
Span.	Distributed Safe Load.
feet.	tons.
20	100 0
22	93 0
24	86 0
26	81 0
28	75 0
30	70 0

5430.

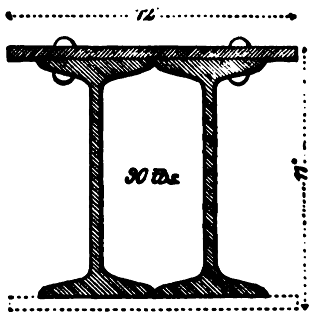


10	13·8
12	11·9
14	10·0
16	8·2
18	7·4
20	6·7
22	5·8
24	5·0

5431.

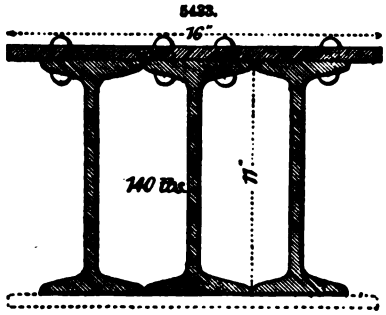


5432.



10	56
12	45
14	38
16	30
18	25
20	22
22	20
24	18
26	16

5433.



10	84
12	69
14	57
16	47
18	38
20	33
22	30
24	27
26	24

thickness of this rib or web is sufficient to add to the strength of the beam, and this marks the difference between a wrought-iron rolled beam and one of similar form, but which is built up of plates and angle-irons. In the latter, the web is supposed to be only thick enough to keep the upper and lower flanges apart and enable them to do their duty, and not of itself to increase the strength of

the beam. There are twc methods of calculating the strength of the rolled beam, so as to include the resistance of the web. By the one, the strength may be first calculated on the assumption that the resistance of the web is nil, and the strength of the web calculated separately as that of a single rectangular beam. The sum of the twc calculations will give the total strength of the beam. By the other, the total strength of the beam is calculated by the ordinary formula, and the resistance of the web allowed for, by increasing the value of the constant. The latter method is the simpler, and, moreover, since it is founded on the assumption that the beam is secured only from lateral deflection, instead of supposing the web to act as an independent beam, is a safer one to adopt. The supposition of the web acting in this matter has not been established by any experiment. The breaking load of wrought-iron rolled beams of the section shown in Fig. 5423, may be thus calculated;—Let W = weight in tons uniformly distributed over the beam which is supported at both ends; A = sectional area in inches, D = depth in inches, L = span in inches, and C a constant equal to 80. Then $W = \frac{2 \times A \times D \times C}{L}$. As an example;—What is the breaking weight in tons uniformly distributed over a rolled beam, having each flange equal to $2\frac{1}{2}$ in. in breadth, by $\frac{1}{4}$ in. in thickness, a depth of 6 in. and a span of 20 ft.? By the formula $W = \frac{2 \times 1 \cdot 25 \times 6 \times 80}{20 \times 12} = 5$ tons. The value of the constant C must never be taken so high as 80, unless the rib is sufficiently thick to prevent the slightest tendency to lateral deflection. In the case of built-up beams, its value should not be greater than 75. The rolled beams are very useful for joists, especially where the floors are required to be fire-proof. They can be rolled in one piece up to about 30 ft. in length, and 15 in. in depth. The breaking weight in tons, uniformly distributed, for rolled beams of different spans and dimensions is given in Table X. The depth and sectional area are in inches.

TABLE X.—STRENGTH OF ROLLED WROUGHT-IRON BEAMS.

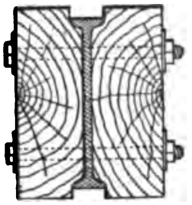
Depth of Beam.	Dimensions of Flange.	Breaking Weights in Tons.				
		Span in feet, 10.	Span in feet, 15.	Span in feet, 20.	Span in feet, 25.	Span in feet, 30.
5	$2 \times \frac{1}{4}$	6 60	4·40	3·30	2·64	2·20
6	$2\frac{1}{2} \times \frac{1}{4}$	10·00	6·60	5·00	4·00	3·30
7	$3 \times \frac{1}{4}$	14·00	9·33	7·00	5·60	4·66
8	$3 \times \frac{5}{16}$	20·00	13·20	10·00	8·00	6·66
9	$4 \times \frac{3}{8}$	36·00	24·00	18·00	14·40	12·00
10	$4\frac{1}{2} \times 1$	60·00	40·00	30·00	24·00	20·00
11	$4\frac{1}{2} \times 1$	66·00	44·00	33·00	26·40	22·00
12	5×1	80·00	52·00	40 00	32·00	26·66
13	6×1	104·60	69·33	52·00	41·60	34·66
14	7×1	130·66	87·11	65·33	52·26	43·55
15	7×1	140·00	93·33	70·00	56·00	46·66

If the value of L be taken in feet, the formula for the breaking weight may be written $W = \frac{13 \cdot 33 \times A \times D}{L}$. We have selected a few of the numerous examples of rolled joists and their combinations from those introduced and manufactured by Measures Bros. and Co. The spans in feet and the safe loads corresponding are annexed. The depth of a rolled girder may be taken somewhat less than in the case of a built-up girder, owing to the much greater lateral stiffness. In the case of girders with narrow flanges they should not be used of a less depth than $\frac{1}{24}$ of the span, but when wide flanges are employed, the ratio, according to the statement of the manufacturer, may be safely reduced to $\frac{1}{30}$. This we do not concur in. From $\frac{1}{18}$ to $\frac{1}{20}$ will be found the most economical proportion, as well as that most in accordance with scientific designing. Where the depth is fixed by the consideration of headway or by other contingencies, and heavy weights have to be supported, two or three girders may be placed side by side, and riveted together with a top and bottom plate covering the whole breadth, as shown in Figs. 5431 to 5433. It must be borne in mind that not quite the whole additional strength is gained by this arrangement, as the plate acts also as a wrapper or cover for the joints existing between the separate beams. The arrangement is, however, occasionally advantageous, as it affords a very stiff girder with a comparatively small depth. For moderate-size sections, the simple rolled girder is to be preferred to the built-up one, but when the depth exceeds a foot, it becomes a question of calculation. Supposing the price a ton of the two beams when complete to be the same, it is clear that, assuming them to be similar in net sectional area and other dimensions, the one which supports the greater load proportionally to its own weight will be the cheaper. There is always a loss in metal in all rolled girders, because the web must be thicker than what is required. As already stated, the increase of thickness does give additional strength to the girder, but not to the same extent as if the superfluous material were removed from the web and transferred to the flanges, where its power of resistance to strain is a maximum. The difference is, that in a built-up girder, we can place the material exactly where we please, whereas we have not so much freedom of design in a rolled beam.

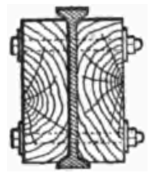
Flitch Beams.—Flitch beams are a combination of timber and iron, and are chiefly employed when but a moderate degree of strength is required, but considerable bearing surface, and a ready means of attaching other timbers and parts of framework. Some examples are shown in Figs. 5434, 5435. Their strength may be thus calculated. Let B and D = breadth and depth of the wood

in inches, T the thickness of the iron plate or flitch, L the span in feet, C a constant, and W the breaking weight in cwts. uniformly distributed over the beam; then $W = \frac{2 D^2 (C B + 30 T)}{L}$. The values for C for different materials are, teak = 4·0, elm = 2·0, fir = 2·5, oak = 3·0. The real strength of a flitch beam in Figs. 5434, 5435, consists in that of the iron; that of the timber counting but little. In addition to being in two pieces, it is also weakened by the bolt-holes passing through it. The strength of the balk in the beam, however, is not seriously impaired, beyond the weakening due to the holes made for the bolts. The French engineers sometimes build up a flitch beam with plates and angle-irons, but in the calculation of the strength, the timber is not taken into account. The simple rolled joist is preferable to the flitch beam, which at the best is but a makeshift, since the timber by itself would not carry the load, and the iron without the support of the timber would give way by lateral flexure. A flitch beam of wood and iron plates makes a very convenient rafter for roofs not exceeding 40 ft. in span, and is, so far as safety is concerned, quite as fire-proof as if it were all of solid iron. It offers superior facilities for attaching the purlins and louver frame, which can be fixed with small wood screws, which do not damage the material. In new countries where timber is cheap, and iron only to be obtained in plain bars and plates, flitch beams can be used with great advantage. They are also much used in warehouses, being frequently built in, or encastré in the walls. Unless protected from the weather, flitch beams are not durable even when the timber is creosoted, although the latter process enables them to last longer than they would do otherwise.

5434.



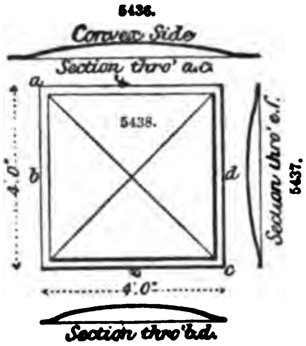
5435.



Buckled Plates.—As a material of construction, Mallet's buckled plates have been very extensively employed, their peculiar form imparting to them great strength and rigidity.

The title, buckled plate, has been given by the inventor to any plate of iron or other metal, the surface of which has been curved or arched, with a very small rise or curvature springing from the edges of the plate in all directions towards the centre, with or without a flat margin all round, such that a transverse section of the plate, in any direction, presents a curved line, as in Figs. 5436 to 5439. Each plate is therefore a very thin and flat polygonal dome or groined arch; the thrusts of an imposed load upon which, in the direction of any two opposite sides, are sustained by the tensions of the outer portions of the adjacent sides of the plate. The flat margin all round is called the fillet.

5436.



5437.

5439.

Such a plate applied as part of a floor, for example, presents a form possessed of great transverse strength and stiffness, when supported and bolted or riveted down round the edges, or supported alone without bolting or riveting down, or supported only at two opposite edges, or even at the corners. Its strength and stiffness are nearly the same, whether the safe load is applied upon the convex or upon the concave side. It also possesses great rigidity and stiffness in every direction in the plane of the plate, so that such plates become an important element of structural strength, when used as bridge flooring. These plates also possess great strength to resist torsion, or the effect of equal and opposite transverse forces applied at adjacent angles of the plate, as shown in Fig. 5438.

The resistance of square buckled plates is directly as the thickness and inversely as the clear bearing. A buckled plate encastré, that is, bolted or riveted down all round, gives double the resistance of the same plate merely supported all round, and if two opposite sides be wholly unsupported, its resistance is reduced in the ratio of 8 to 5. Within the limit of safe load the resistance is nearly the same, whether it be upon the crown or uniformly diffused. The stiffness at any point of the plate, as against unequal loading, is as the square of the thickness nearly, and inversely as the curvature. The curvature, unless for special object, should never exceed that which will just prevent the crippling load bringing the plate down flat, by compression of the material; less than 2 in. versed line of curvature has been found sufficient for ¼-in. buckled plate 4 ft. square.

A 3-ft. square buckled plate, of ordinary Staffordshire iron ¼ in. thick, 2 in. in width of fillet, 1⅜ in. curvature, supported only all round, requires upwards of 9 tons diffused over about half the superficies at the crown to cripple it down, and double this, or 18 tons, to cripple it if firmly bolted or riveted down to rigid framing all round. A similar plate of soft puddled steel has been found to bear nearly double the preceding, or 35 tons, to the square yard. The buckled plates of the floor of Westminster new bridge, each averaging 7 ft. by 3 ft., ¼ in. thick, and 3¼ in. curvature, were tested by lowering upon the crown of each a block of granite of 17 tons weight, which they sustained without injury. In structures exposed to impulsive loads, such as railway or other bridge flooring, one-sixth of these crippling loads should not be exceeded for the safe load, nor one-fourth for quiescent loading.

The floors of fire-proof buildings formed of thin buckled plates, laid on wrought-iron girders and cross-joists, and covered with a stratum of 4 or 5 in. of concrete, with a tiled, slate, boarded or other floor surface above, constitute a good fire-proof construction. As compared with the common system of brick arching on iron beams, such flooring presents the advantages of reduced thickness and weight, and relief of the walls from all thrust or strain by expansion.

Buckled plates may readily be galvanized, either before or after buckling. Unless out of reach of the moist and saline atmosphere, extending some miles from all sea-coasts, and remote from the still more destructive action of the sulphur acids in the air of our coal-consuming cities, galvanizing is not always a certain protection to iron from corrosion.

Rolled, plate, or sheet iron, is the material of which buckled plates are formed. Buckled plates of thin sheet zinc, in tiles 2 ft. square, form roof coverings of strength, lightness, and elegance. The adaptation of puddled steel as a material for buckled plates has lately opened a new field for their applications. Such plates possess double the stiffness and tenacity, and more than double the resistance to compression of rolled iron of equal dimensions.

The size of buckled plates formed of one single rolled plate, is only limited by the breadth to which sheet or plate iron can be rolled, at market prices; and the sizes that have been found most advantageous for the majority of purposes, are plates of 3 ft. and of 4 ft. square, or of those widths by the full length of the sheet. Compound plates, possessing the properties of buckled plates, may be formed by uniting into one several smaller curved plates; and such large or compound buckle-plates, for roofs and floors of prison cells instead of arching, and for water-tanks.

Square plates of either of the two ordinary market sizes are always to be preferred, on the ground of economy in prime cost, and in application, and in being obtained with facility. Square plates produce a stronger floor, with a given weight of iron, than any other form. The resistance of the latter being that nearly of a square plate, whose side is equal the longer dimension. Buckled plates of 3 ft. or of 4 ft. square can be readily adapted to the framing of any structure. If rectangular plates are used, the longer edge should not be much more in length than twice the shorter.

Buckled plates may be united to each other, or to the frame of the structure they cover, by either lap or butt joints, as shown in Figs 5440, 5441, either by screw-bolts, rivets, or wood screws, and the joints are made absolutely water-tight, when required, by riveting and chinking up; by interposed strips of tape or of felt, saturated in oil cement, or in tar and pitch; by strips of vulcanized india-rubber, or by a thin layer of oil putty. Economy is always consulted by supporting each plate all round, one pair of opposite fillets resting on the girders or joists of the structure, and the joints of the cross fillets supported by an angle-iron above, thus forming a lap-plate.

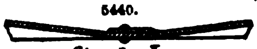
Table of Strength and Weight of Buckled Plates.

No.	Thickness of Plate.	Weight a square yard of Buckled Plate.	Weight of an equal surface, 1 square yard, of Corrugated Plate of corresponding thickness.	Safe passive Load, uniformly diffused a square yard, for 3 feet square Buckled Plates.	Safe impulsive Load, uniformly diffused a square yard, for 3 feet square Buckled Plates.	Nearest number of square yards in 1 ton of Buckled Plates.
	B. W. G. in.	lbs.	lbs.	tons.	tons.	sq. yds.
1	No. 18 = ·048	17·3	20·7	0·27	0 20	129
2	No. 16 = ·066	23·6	28·3	0·43	0·32	95
3	No. 12 = ·107	38·7	46·4	0·64	0·48	57
4	" $\frac{1}{8}$	45·0	54·0	1·0	0·75	49
5	" $\frac{3}{16}$	67·5	81·0	2·5	1·7	33
6	" $\frac{1}{4}$	90·0	108·0	4·5	3·0	24
7	" $\frac{5}{16}$	112·5	135·0	6·2	4·7	20
8	" $\frac{3}{8}$	135·0	162·0	9·0	6·8	16

The safe loads, in columns 5 and 6, may be taken at double for buckled plates of puddled steel.

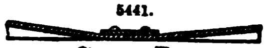
In Figs. 5440 to 5444 are shown the different methods of forming joints with the buckled plates. They are all good, with perhaps the exception of Fig. 5444, as the fillet of the plate which overlaps

5440.



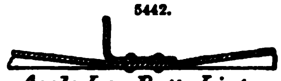
Simple Lap.

5441.



Simple Butt.

5442.



Angle Iron Butt Joint.

5443.

T Iron Butt Joint.

5444.

Lap with Edge of Plate turned up to Stiffen.

the other would require especial workmanship and consequently entail extra cost. Besides, the same purpose would be equally well answered by employing an ordinary angle or T iron.

Corrugated Iron.—Little or no information exists with respect to the strength of corrugated iron, but the following experiments, by J. H. E. Hart, of the P. W. D. India, on its transverse strength will be found valuable. The iron was supposed to be of the following gauges;—8 BWG, 10 BWG, 12 BWG, 16 BWG, 22 BWG. The sheets or plates were supported on trestles, and loaded in their middle by weights suspended in a scale pan. The bending action of the load was distributed along the transverse axis by a rigid bar of timber laid across the sheet at right angles to the corrugations, and the pressure of this bar was distributed to ridge and furrow by a layer of damp sand. Fastened to this bar by a cotter was a flat strip of steel, which, passing

through a slot in the sheets, suspended a stirrup with a universal joint carrying a roughly-made scale beam. The dimensions of the slot were ⅜ in. long by ¼ in. wide.

The object of this arrangement was to obviate any unequal strain on one side or other of the sheets, through the oscillations of the load in the scale pan. The trestles were movable along sleepers sunk in the ground, so that the bearings of the sheets could be altered at pleasure. The deflections were measured with a scale of 50ths of an inch, which was hung from the lower side of the sheets, between silk threads stretched by weights between the trestles. The thicknesses of the sheets were measured with a scale of 100th of an inch, read off with a magnifying glass. The sheets broken were of various breadths in order to test the accuracy of the formula; for the same reason the bearings were made to vary; and in order that the comparison might be closer, several of the broken sheets were again subjected to experiment. The constant, or modulus of rupture, arrived at is on the whole sufficiently uniform, and establishes fairly Rankine's approximate formula, for the moment of resistance of corrugated iron, given in his Manual of Civil Engineering;—

$$\frac{4}{15} f_a \, h \, b \, t \ldots$$

which equated with the bending moment for a central load gives

$$\frac{4}{15} f_a \, h \, b \, t = \frac{W\,l}{4}, \text{ whence } f_a = \frac{15}{16} \frac{W\,l}{h\,b\,t},$$

by which formula the modulus of rupture f_a is calculated.

In the formula;—

W = The total load in pounds;
h = The height of the corrugations measured from ridge to furrow;
b and t = The breadth and thickness respectively of the sheets in inches;
l = The bearing or span between supports in inches.

The heights of the corrugations were found to be very unequal, not only in adjacent ridges and furrows, but also in different parts of the same furrow. The heights given in the data are the average of all across the sheet in the middle, as shown in the sketches of the section in Figs. 5445 to 5457. The outer corrugations, unless the plate was expressly cut, were not of the full depth, and their heights were rejected as an element of strength. The thicknesses varied in different sheets of the same gauge, and also slightly in different parts of the same sheet. They were measured from a piece cut out of the sheet, and carefully filed true; in few cases, however, did they correspond with the tabular value of the thickness of the supposed gauge of the sheets. The placing and removal of the loading was effected through the medium of a lever and screw-jack, which arrangement obviated any chance of a jar of the material from jerks or vibrations of the load. Every care was taken to avoid inaccuracy, either of observation or of result.

No. of Experiment.	Description of Sheet.	Weight in lbs.	Deflection in inches.	Dimensions of Sheet, and Remarks.
1	Gauge No. 22	164	·60	t = ·029 in.
		220	·82	l = 60 in.
	Size of sheet 8′ × 2′ 3″	234	·88	b = 27 in.
	Weight of sheet 28 lbs.	248	·92	h = ·67 ∴ f_a = 46567 lbs.
	„ a sq. ft. = 1·56 lb... ..	262	1·00	on sq. in.
		276	1·08	
		290	1·14	Yielded slowly on adding
		304	1·22	last weight by tearing of
		430	broke	lower corrugations on
				each side of slot in
				middle.

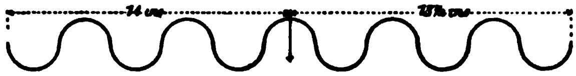
5445.

2	Gauge No. 20..	90	·18	t = ·085 in.
		146	·28	l = 60
	Size of sheet 6′ × 2′ 7⅝″	202	·40	b = 31·75 ∴ f_a = 45628
	Weight of sheet 29 lbs...	258	·52	h = ·71
	„ a sq. ft. = 1·83 lb.. ..	314	·64	
		370	·78	
		426	·96	
			ultimate	
		640	6·8	
		641	broke	

5446.

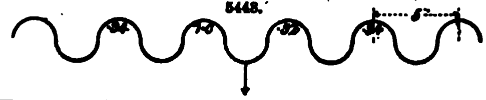
No. of Experiment.	Description of Sheet.	Weight in lbs.	Deflection in inches.	Dimensions of Sheet, and Remarks.
2a	Uninjured end of above sheet re-broken..	1448	broke	$l = 30$ in. $h = \cdot72 \therefore f_a = 50900$
3	Gauge No. 17..	·46	·08	$t = \cdot06$ in.
		102	·12	$l = 60$
	Size of sheet 6' × 2' 3½"	158	·20	$b = 27\cdot5 \therefore f_a = 41663$
	Weight of sheet 38 lbs.	214	·31	$h = \cdot95$
	„ a sq. ft. = 2·76 lbs. ..	382	·40	
		1161	broke	Two separate sheets with weight hung between the right-hand sheet failed first.

5447.



3a	Uninjured end of above sheet re-broken..	1018	broke	$1 = 30$ $h = \cdot86$ $b = 3\cdot5 \therefore f_a = 41101$
4	Gauge No. 17..	160	·12	$t = \cdot06$ in.
		272	·22	$l = 60$
	Size of sheet 6' × 2' 3¾"	384	·34	$b = 27\cdot75 \therefore f_a = 43528$
	Weight of sheet 38½ lbs.	496	·46	$h = \cdot95$
	„ a sq. ft. = 2·77 lbs... ..	720	·72	Yielded slowly with puckering of the top corrugation and spreading at sides.
		1224	broke	

5448.

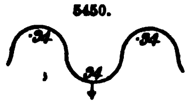


5	Gauge No. 13 or 12	260	·28	$t = \cdot096$ in.
		596	·46	$l = 60$
	Size of sheet 6' × 2' 9"..	1044	·68	$b = 33$
	Weight of sheet	1794	a	$h = \cdot9$
	„ a sq. ft.	1895	c	a here received a shock from slipping of lifting tackle.
		2114	d	c Ditto ditto.
		2160	broke	d plate began to sink visibly, giving most at side where h was least.

5449.

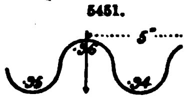
6	Gauge No. 12..	151	·12	$t = \cdot1$ in.
		263	·20	$l = 48$
	Size of sheet 6' 0¼" × 0' 10·1" ..	375	·30	$b = 10\cdot1 \therefore f_a = 49770$
	Weight of sheet 24·5 lbs.	487	·38	$h = \cdot94$
	„ a sq. ft. 4·84	599	·46	
		1050		

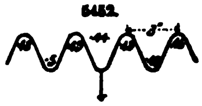
5450.



6a	Uninjured ends of above sheet re-broken	1768		$l = 30 \therefore f_a = 52376\cdot4$
6b		2210		$l = 24 \therefore f_a = 52374\cdot6$
7	Gauge No. 12	152	·10	$t = \cdot1$ in.
		264	·18	$l = 48$
	Size of sheet 6' 0¼" × 0' 9·9" ..	376	·26	$b = 9\cdot9 \therefore f_a = 46124\cdot4$
	Weight of sheet 23·5 lbs.	488	·30	$h = \cdot95$
	„ a sq. ft. 4·73 lbs.	600	·44	
		768	·60	
		964	broke	

5451.



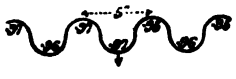
No. of Experiment.	Description of Sheet.	Weight in lbs.	Deflection in inches.	Dimensions of Sheet, and Remarks
8	Gauge No. 13 or 12 .. .. .. Size of sheet 6′ × 1 .. .. .. Weight of sheet 27 lbs. .. .. „ a sq. ft. 4 50 lbs.	90 146 202 258 314 428	·44 ·72 1·0 1 36 1·8 broke	$t =$ 095 in. $l = 60$ $b = 12 \therefore f_a = 43099$ $h =$ 49 5452. 
9	Gauge No. 13 or 12 .. .. .. Size of sheet 6′ × 1′ .. .. .. Weight of sheet 28 lbs. .. .. „ a sq. ft. 4 66 lbs. .. .. 5453. 	90 146 202 258 314 426 480 483	·34 ·58 80 1·04 1·26 2·10 ultimate 2·78 broke	$t =$ 095 in. $l = 60$ $b = 12 \therefore f_a =$ 41959 4 $h = 56$ These two sheets 8 and 9 are rolled to sharper curves at the corrugations than others, and approach the zigzag form. They are also got from the same whole sheet cut in half, and show a curious discrepancy in the height of corrugations.
10	Gauge No. 12 or 11 .. .. .. Size of sheet 6′ × 2′ 9″ .. .. Weight of sheet 103 lbs. .. .. „ a sq. ft. 6·24 lbs.	212 436 660 884 1108 1332 1780 4000	·12 20 26 32 ·36 ·44 ·56 broke	$t =$ ·12 in. $l = 60$ $b = 33 \therefore f_a = 58940$ $h =$ ·964

5454.

No. of Experiment.	Description of Sheet.	Weight in lbs.	Deflection in inches.	Dimensions of Sheet, and Remarks
11	Gauge No. 12 or 11 .. .. .. Size of sheet 6′ × 2′ 9″ .. .. .. Weight of sheet 88 lbs. .. .. „ a sq. ft. 5·34 lbs.	90 202 426 650 762 900 1251 2750 3072	·06 ·10 ·20 ·30 ·34 ·40 ·58a ·18 broke b	$t =$ ·115 in. $l = 60$ $b = 33 \therefore f_a = 46378$ $h =$ ·964 a, Load removed, plate returned to the horizontal. b, Ultimate deflection observed at 3000 was 4·6″

5455.

No. of Experiment.	Description of Sheet.	Weight in lbs.	Deflection in inches.	Dimensions of Sheet, and Remarks
12	Gauge No. 9 .. .. Size of sheet 6′ × 1′ 3″ .. .. .. Weight of sheet 49 lbs. .. .. „ a sq. ft. 6·53 lbs. .. .. 5456. 	202 426 650 874 1110 1334 1558 1850	·18 ·36 ·50 ·60 ·84 1·02 1·40 broke	$t =$ ·15 in. $l = 60$ $b = 15 \therefore f_a = 47760$ $h =$ ·97

No. of Experiment.	Description of Sheet.	Weight in lbs.	Deflection in inches.	Dimensions of Sheet, and Remarks.
13	Gauge No. 2	202	·20	$t =$ ·15 in.
		426a	·36	$l = 60$
	Size of sheet 6′ × 1′ 3″	650	·52	$b = 15 \therefore f_a = 43281$
	Weight of sheet $47\frac{2}{3}$ lbs.	874	·64	$h =$ ·96
	" a sq. ft. 6·36 lbs... ..	1098	·80	
		1322b	1·02	a, Outer edge began to cripple.
	5457. 		ult. def.	
		1660	2·84	b, Load removed and sheet returned to deflection of ·04 only.
		1662	broke	

Mean value of $f_a = 46682$ from all experiments, or $= 45916$ omitting No. 10.

It appears from these experiments that the highest and lowest values of fa are respectively 58940 and 41101; the former of these extreme values is open to suspicion, because of the great discrepancy between the breaking load of it and its sister sheet, No. 11. The mean value of fa from the remaining experiments would be, as nearly as might be, 46000, and this may be adopted as its true value. Experiments 2, 2a, and 6, 6a, show that the strength varies inversely as the length, although a slight increase of strength appears in the shorter sheets, which may be accounted for by the deflection being less. The breadth does not appear to influence the constant, so that we may assume the strength to vary as this dimension. The depth also of corrugation does not appear to influence the result other than directly; this is, however, a point that could only be examined by having similar sheets rolled of varying depths of corrugations. However, Experiments 5, 8, and 9, afford a comparison as far as they go. Experiments 6, 7, 12, and 13, show that in narrow sheets the position of the side edge, whether in tension or compression, makes a difference. This is a necessary consequence of the laws of the strength of materials, and it was observable that when the side edges of the plates were up, as in Experiment 7, the edges crippled early in the experiment; while when they were down, as in Experiment 6, they did not fail till later. All plates first showed symptoms of failure at the side edges. None of the plates gave way suddenly, but each sank slowly when the breaking weight had been reached. As a rule, they appeared to fail by the spreading of the corrugations at the middle, and did not crush at the tops of the ridges; on the contrary, when the sheet was allowed to sink till rupture of the material took place, fracture occurred by tearing of the furrow commencing from each side of the central slot, and proceeding towards the sides of the sheet at right angles to the length.

It is probable that had the sheet been prevented from spreading by strips riveted across it, as recommended by Rankine, the constant would have increased in value. In bridges, the adjoining sheets would act so as to oppose the spreading, and this may be looked upon as an element of strength. The results of the observations of the deflections seem to be uniform, but at present no deductions from them are made. The ultimate deflections were in a few instances observed as a matter of curiosity, but in most cases it was not possible to hit off the very extreme deflections.

Concluding Remarks.—It has often been asserted that our knowledge, with respect to a subject so important as that we have just considered, is very imperfect. To a certain extent the assertion is true. It cannot be denied that although we possess an amount of knowledge relative to the subject, which is sufficient to enable us to design any structure with safety, yet it is very doubtful if the greatest amount of economy is also ensured. When authorities differ with regard to the strength of any material or combination of materials, the obviously only safe plan for the engineer or architect to adopt is to allow a large margin, which, in numerous instances, is excessive. Hence arises a considerable waste of material, and, moreover, a want of confidence in the design, which is extremely unsatisfactory to the designer. It is now close upon thirty years since any series of experiments, bearing the stamp of Government authority, has been carried out. Since that period, the art of construction has undergone many modifications and been subjected to several innovations. A series of international experiments upon the strength of materials, to be carried out by a committee of eminent scientific and professional men appointed by the principal Governments, would be of the greatest value to the cause of science and technical education. It is not enough to design a structure so that it shall be sufficiently strong for its purpose, but to design it so that it shall be no stronger than necessary, and thus solve the great problem, which is tc ensure the greatest amount of strength with the least amount of material.

Books on the Strength of Materials;—Turnbull (W.), 'On thc Strength ot Cast-Iron Beams,' 8vo, 1832. Turnbull (W.), 'On the Strength and Stiffness of Timber,' 8vo, 1833. 'Report of the Commissioners appointed to Inquire into the Application of Iron to Railway Structures,' 2 vols. folio, 1849. Tate (J.), 'On the Strength of Materials,' 8vo, 1850. Clark (E.), 'Britannia and Conway Bridges,' 8vo, 1850. Tredgold and Hodgkinson 'On the Strength of Cast Iron and other Metals,' 8vo, 1861. Belanger (J. B.), 'Théorie de la Résistance des Solides,' 8vo, Paris, 1862. Morin (A.), 'Résistance des Matériaux,' 2 vols. 8vo, Paris, 1862. Kirkaldy (D.), 'Experiments on Wrought Iron and Steel, 8vo, 1864. 'Leçons sur la Résistance des Matériaux,' par Nayier, avec Notes et Appendices par M. Barre de St. Venant, Paris, 1864. Barlow (P.), 'On the Strength of Materials,'

8vo, 1867. Baker (B.), 'On the Strengths of Beams, Columns, and Arches,' crown 8vo, 1870. Fairbairn (W.), 'The Application of Cast and Wrought Iron to Building Purposes,' 8vo, 1870. 'Tredgold's Carpentry,' by J. T. Hurst, crown 8vo, 1871. Wood (De Volson), 'Treatise on the Resistance of Materials,' 8vo, New York, 1871. Anderson (J.), 'The Strength of Materials and Structures,' 12mo, 1872. Donaldson (W.), 'New Formulas for the Loads and Deflections of Solid Beams and Girders,' 8vo, 1872. Pole (W.), 'Iron as a Material of Construction,' crown 8vo, 1872. Rankine (W. J. M.), 'Applied Mechanics,' 1872. Stoney (B. B.), 'Theory of Strains,' 8vo, 1873. Cargill (T.), 'Strains upon Bridge Girders and Roof Trusses,' 8vo, 1873.

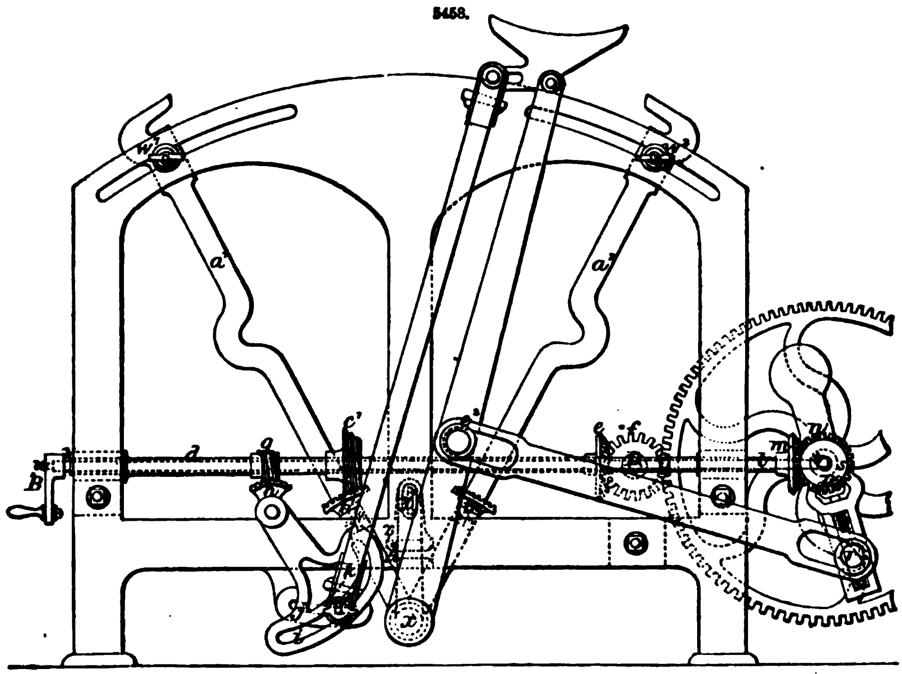
MEASURING AND FOLDING.

W. H. and T. Hacking's Folding and Measuring Machine, Figs. 5458 to 5464.—The novelty in this machine consists in an arrangement of worm shafts and wheels by means of which the rails used for holding the folded cloth are moved simultaneously and by one operation to suit the various lengths of folds required to be made, this arrangement being applicable, with slight modifications to either flat or circular tables; and in an arrangement of bevel-wheels and shafts by which the crank studs which determine the length of the stroke of the folding arms, and consequently the length of the fold, are moved simultaneously and by one operation.

Hackings also use double folders or plaiting knives placed one above the other about half an inch apart, and fingers actuated by cams and springs which lay hold of and retain the cloth at the end of each fold, the fingers being made to lay hold of the cloth between the double folders and in the interstices between them; combined with an arrangement of parallel bars, cranks and side arms, by means of which the folders or plaiting arms are made to fold cloth on flat tables. Also fingers working in recesses in the folding knives for holding the cloth securely when folded: these fingers being raised by cams and pulled down by springs.

Fig. 5458 represents an end elevation of a circular top folding and measuring machine having Hackings' improvements attached. Figs. 5459 to 5461 are detached elevations of some of the parts; Figs. 5462, 5463, the end and front elevations; and Fig. 5464, a plan of a flat top folding and measuring machine.

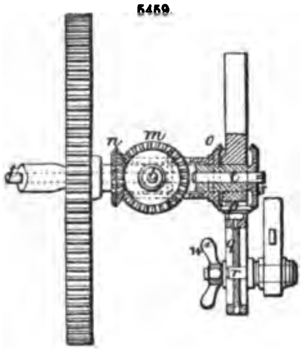
5458.



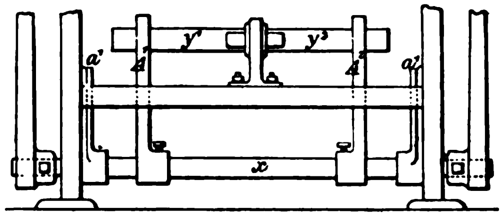
In Fig. 5458 the ordinary card rail brackets are shown prolonged by arms at a^1, a^2, terminating in bosses bored to fit loose on the ordinary rocking shaft x. On the arms a^1, a^2, are fixed quadrants b^1, b^2, being segments of worm-wheels, having the centre of the shafts x for a common centre. Gearing into the quadrants b^1, b^2, are two conical worms c^1, c^2, one being a right-hand worm, and the other left hand. These worms c^1 and c^2 are fixed on the hollow shaft d. When the shaft d is turned round by means of the handle B, which fits on the square v of the shaft d, the arms a^1, a^2, are caused to approach or recede from one another according to the direction in which the handle is turned. On the shaft d is also fixed a worm g, which gears into a quadrant h working on a stud. This quadrant has an arm attached to it, and a curved slot i which clips the stud of the ordinary swivel arm k, and by the rotation of the shaft d causes the stud of the swivel arm to move in the slot j. The quadrants b^1, b^2, and the quadrant h are proportioned to work in unison with each other, so that the rotation of the shaft d causes the swivel arm k to take the right position for the length of fold to which the arms a^1, a^2, are moved.

On the shaft *d* is also placed a mitre-wheel *e* gearing into a mitre-wheel of similar size *f* placed on the shaft D, which extends across the machine. On the opposite end of the shaft D is placed a mitre-wheel corresponding to *f*, which gears into another mitre-wheel corresponding to *e* placed on a shaft corresponding to the shaft *d*, upon which are placed worms corresponding to c^1, c^2, and *g*, gearing into quadrants corresponding to b^1, b^2, and *h*, attached to the card rail brackets and swivel arms on the opposite side of the machine. By the train of wheels thus described the card rail brackets a^1, a^2, and the corresponding card rail brackets on the other end of the machine, the swivel arm *k*, and the corresponding swivel arm at the other end of the machine, are all moved simultaneously by the rotation of the shaft *d*.

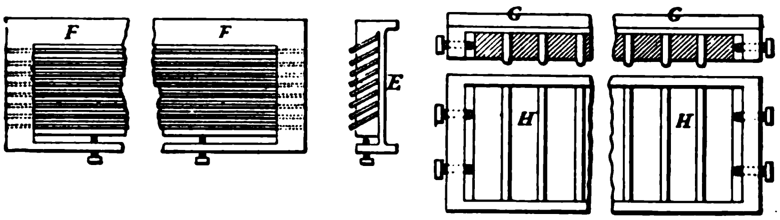
5459.



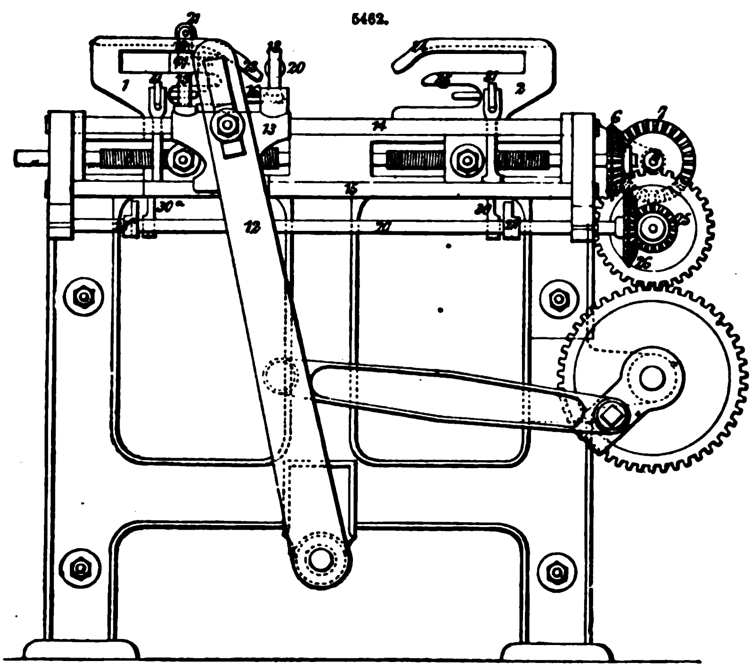
5460.



5461.



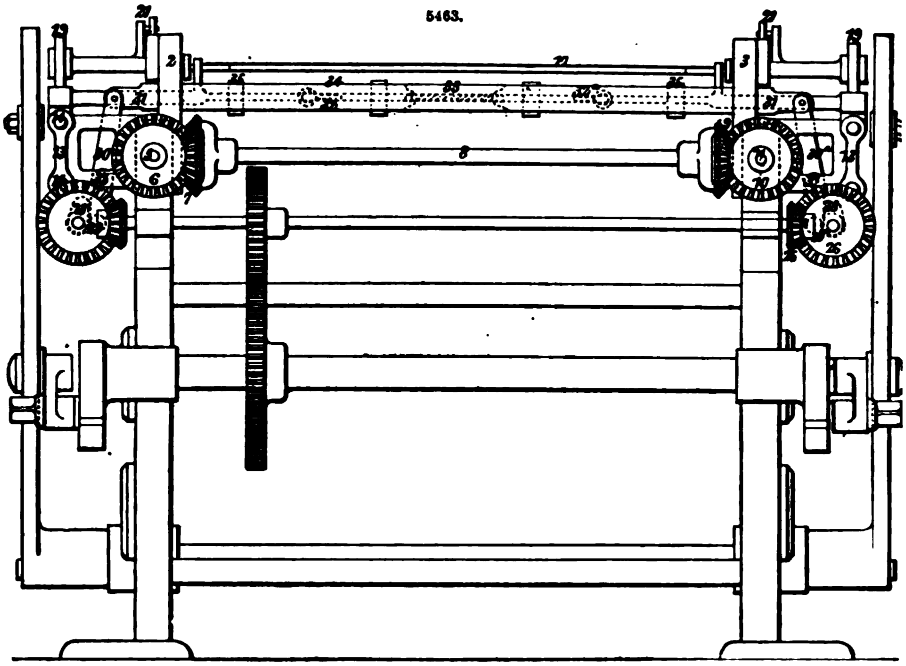
5462.



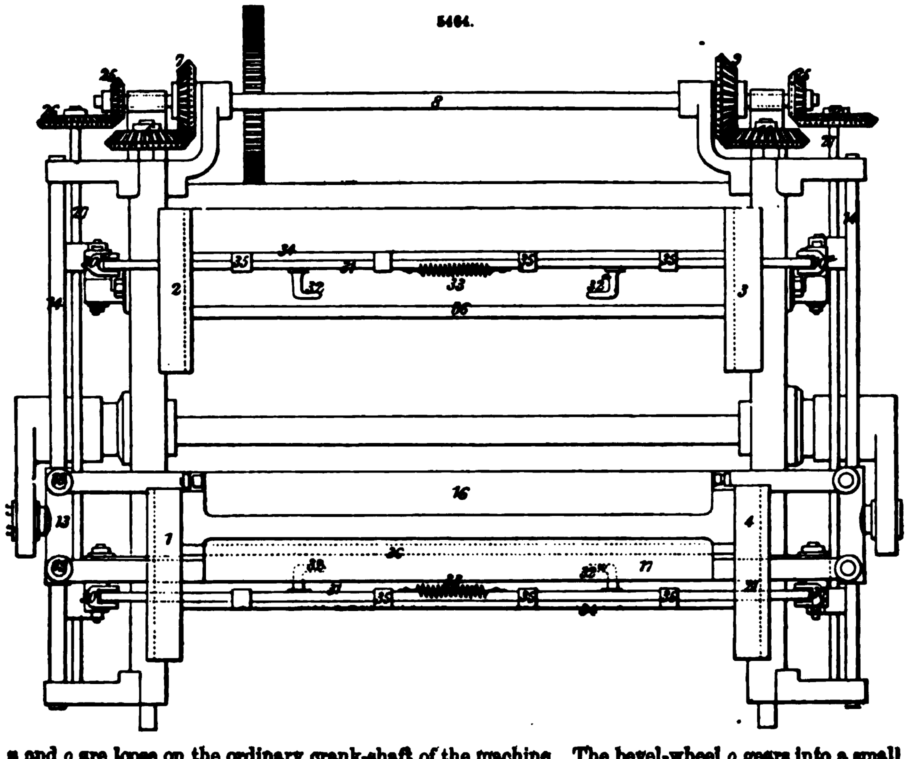
In the interior of the hollow shaft *d* is placed a small shaft *l*, *l*, Figs. 5458, 5459, one end of which projects at *u*, Fig. 5458, and is made square so as to fit in the smaller recess of the handle B. At

the other end of the shaft l is placed the bevel-wheel m gearing into another bevel-wheel n Fig. 5459, which has a long boss and another bevel-wheel o attached to it. The bevel-wheels

5463.



5464.



n and o are loose on the ordinary crank-shaft of the machine. The bevel-wheel o gears into a small bevel-wheel p placed at the end of the crank-screw q, and to which is attached in the ordinary way

the crank-stud r. By this apparatus the crank-stud r is shifted to give the required movement to the knives of the machine by the rotation of the shaft l turned by means of the handle B, and acting on the train of wheels m, n, o, and p. The bevel-wheel p, Fig. 5459, gears into another bevel-wheel s, which is fastened to a shaft t passing through the centre of the crank-shaft, and having at its opposite end another bevel-wheel corresponding to the wheel s, gearing into another bevel-wheel corresponding to the wheel p, placed at the end of the crank-screw at the opposite end of the machine, by which means both the crank-studs are moved simultaneously.

The handle B, Fig. 5458, has in it two recesses, one fitting on the square u, and the other on the square v, so that both shafts d and l can be turned simultaneously by the same handle B; and the sizes of the bevel-wheels m, n, o, p, are proportioned to the segments b^1, b^2, and h, so that the rotation of the shafts d and l together move in unison the four card rail arms, the two swivel arms, and the two crank-studs, so that each part retains its proper working adjustment in respect of the others. Instead of the ordinary nuts, Hackings employ winged or thumb nuts, as at w^1, w^2, w^3, w^4, for the purpose of attaching the card rail brackets, swivel arms, and the crank-studs in their places. By this means they are enabled to alter the machine for a different length of fold without the aid of a screw-key.

In Figs. 5458, 5460, y^1, y^2, represent a tempered spring carried by the bracket z fixed on the bottom cross rail of the machine. A^1, A^2, are two arms fixed by means of screws to the rocking shaft x, having slots in them through which the ends of the springs y^1, y^2, are passed. When the machine is set in motion the arms A^1, A^2, are oscillated by means of the shaft x, and have to overcome the resistance of the spring y^1, y^2. The strength of the spring y^1, y^2, is proportioned to the weight of the side and swivel arms, and through the medium of A^1, A^2, and x acts as a counterpoise to them, enabling the driving pulley of the machine to be turned with about the same amount of power in all positions of the side arms.

In Fig. 5461 a section of an improved card rail is shown at E, and a plan of the same at F. The space usually filled with card is here filled with alternate strips of india-rubber and wood, placed at an angle to the rail. These strips of india-rubber and wood are shown as going in a parallel direction with the card rail at E and F. A modification of the same arrangement is shown at G, H, in which the alternate strips of india-rubber and wood, instead of being placed parallel with the card rail, are placed transversely. Hackings also use, in lieu of the ordinary card, india-rubber backed with strong cloth, and covered on the face with coarse or fine emery or glass to prevent injury to bleached and finished fabrics. In Figs. 5462 to 5464 the card rail bracket is shown at 1, 2, 3, 4 and is attached to the screw 5, 5^a, by means of a boss tapped to the same pitch as the screw. The screw 5, 5^a, is made with a left-hand thread one portion of its length, and with a right hand for the other. On the extremity of 5 is placed a mitre-wheel 6, gearing into another mitre-wheel 7 placed on the shaft 8, extending across the machine, and having at its opposite extremity another mitre-wheel 9 gearing into another mitre-wheel 10, which actuates a screw 11 corresponding to 5, 5^a. By this means the rotation of the screw 5, 5^a, causes all the card rail brackets, 1, 2, 3, and 4 to approach or recede from one another according to the direction in which it is turned.

The ordinary side arm 12 made to oscillate in the usual manner by means of a crank communicates motion to the knife-bracket 13, which moves in a horizontal manner on the rods 14, 15. The bracket 13 has on it two pillars or studs 18, 19, on which the knives 16, 17, are so placed that they can be made to move up and down on the studs 18, 19, by means of bowls and inclines shown at 20, 21, 23, 24, in a similar manner to the arrangement made by S. Knowles and R. Hayward.

On the first motion shaft is placed a bevel-wheel 25, gearing into another bevel-wheel 26, placed on a shaft 27, running along the end of the machine, and driven at the same speed as the crank-shaft. On the shaft 27 are placed two cams 28, 28^a, of the shape shown in Fig. 5463. These cams act on the bowls 29, 29^a, placed at one extremity of the levers 30, 30^a, carried on the shaft 37. The other extremity of the levers 30, 30^a, is attached to sliding bars 31 passing through the card rail brackets 1, 2, 3, 4, and supported by brackets 35 fixed on the rails 34.

The sliding bars have on them adjustable hooks or bent fingers 32, 32^a, shown at Fig. 5464; the bars are also in two parts in the width of the machine, as in Figs. 5463, 5464, and are connected in the centre of the spiral springs 33.

The mode of working this combination is as follows;—When a piece of cloth is to be folded and measured the fingers 32, 32^a, are set so that they will hook or lay hold of the selvages of the cloth. As the knife 16, bringing with it the cloth in the usual manner, approaches the card rail bracket 1, the fingers 32, 32^a, are drawn out beyond the width of the cloth by means of the levers 30^a and the cams 28^a. When the knife 16 has arrived at the end of its stroke in the direction of the card rail bracket 1, the cam is shaped so as suddenly to release the lever 30^a, and the spring 33 draws the fingers 32, 32^a, so as to lay hold of and retain the selvages of the cloth carried by the knife 16. The knives 16, 17, are bent in a U form, Fig. 5462, so as to allow the finger to lay hold of the cloth in the hollow formed by the bend of the knives. As the knife 17, carrying with it the cloth to be folded, approaches the card rail bracket 2, a similar movement of the fingers is effected by means of the cams 28 and levers 30.

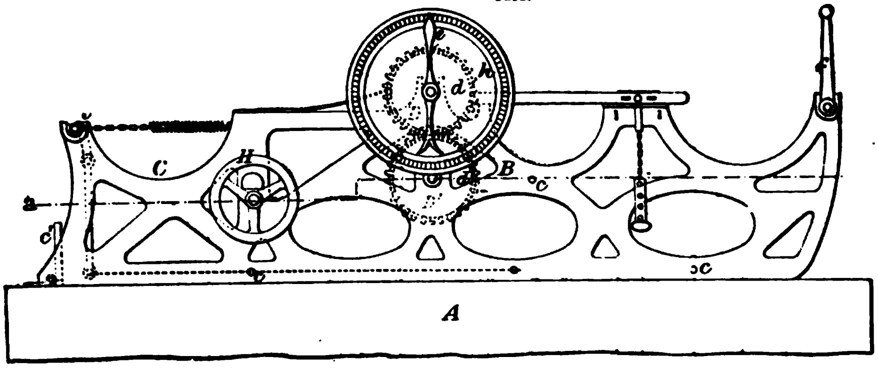
The rails 36 are for the purpose of retaining the folded cloth in its position when the fingers 32, 32^a, are drawn out

Wm Boase's measuring and folding machine, Figs. 5465 to 5468, is so arranged as to enable the complete and self-contained machine to be placed upon a shop counter for ordinary retail use.

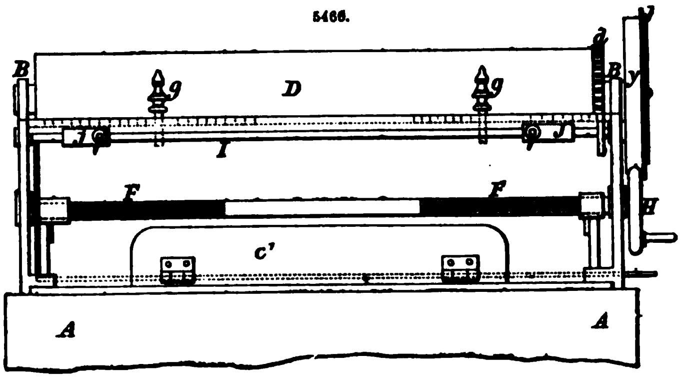
A, A, is the upper portion of the counter or platform upon which the machine is fitted; B, B, is the framing, made by preference of cast iron, and containing the whole of the mechanism. This framing is formed by two side frames B, B, consisting of an iron web and suitable strengthening ribs, and fitted upon the counter; and the side frames B, B, may be tied and held together by means of a number of stays or cross bars c, c. They also form the seats for the bearings of all the axles or spindles required for the machine. The framings of the machine are usually 4 ft. 6 in. long, and placed 3 ft. 2 in. apart. C is the receptacle into which the goods or fabrics about to be

measured are placed, either loose or rolled on a roller, or blocked on a board, as the case may be; the outer part of the casing C forming a reversible shutter c^1. D, D^1, are the two rollers between

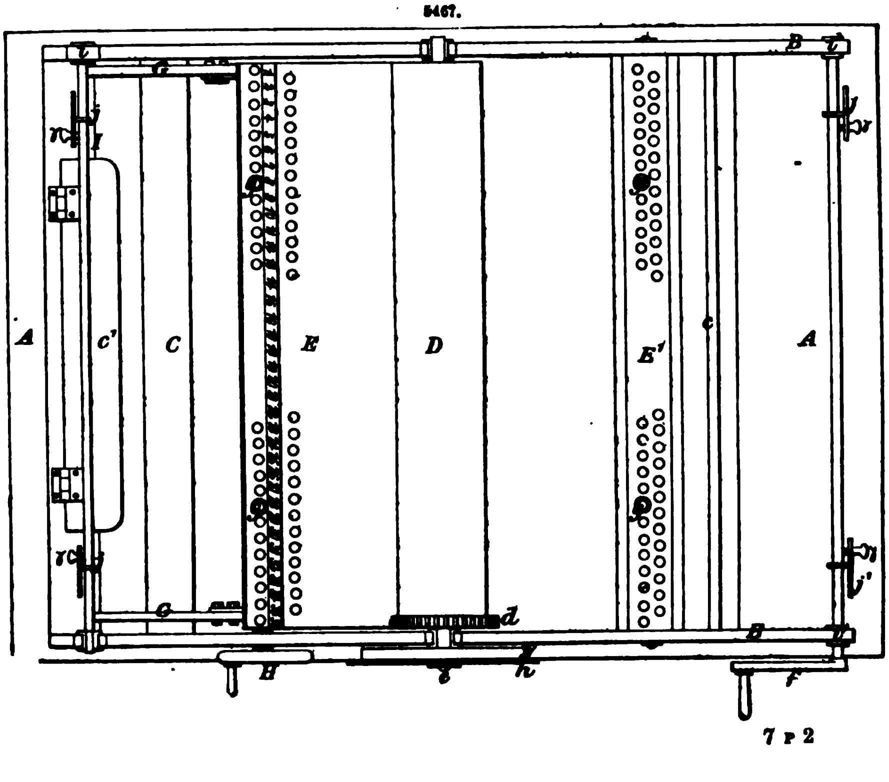
5465.



5466.

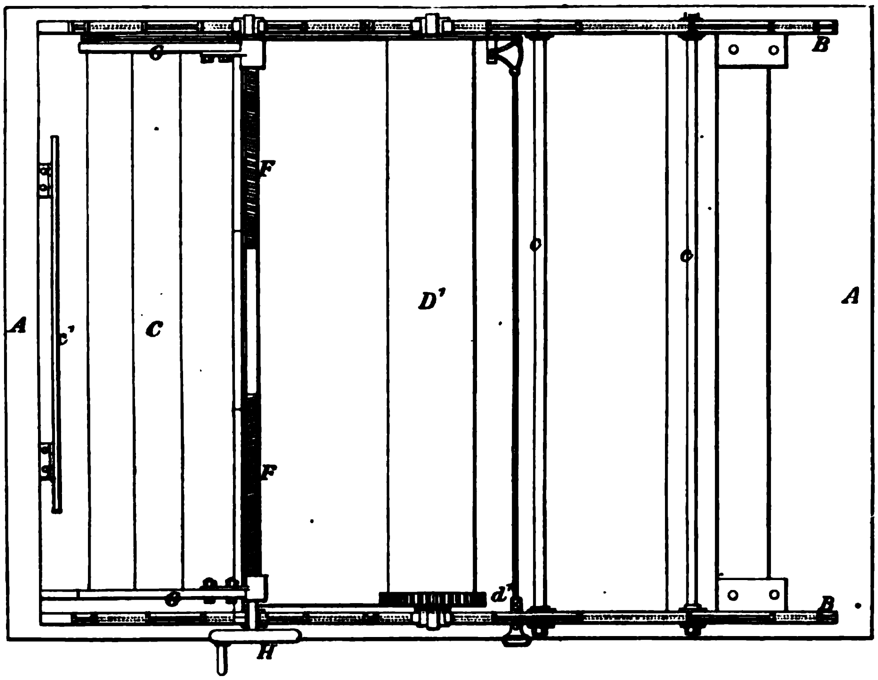


5467.



which the fabric passes while the process of measuring is taking place. The upper roller D is removable and its axis adjustable by means of springs, so that this roller is continually kept in close contact with the lower roller D^1. Upon the axis of each of the two rollers a toothed wheel is fixed, both wheels d, d^1, forming together a gearing calculated to assist in the transmission of the motion from one roller to the other.

5468.



The extremity of the axis of the top roller D has fitted upon it an indicator hand or pointer e, denoting, on a dial h connected with the gearing, the number of yards, mètres, ells, or other units of measure over which the stuff or fabric has travelled during the operation. The fabric having passed between the rollers D, D^1, will be wound up on a roller or blocked on a board connected with the axis l^1 set in motion by hand by means of a crank f, the arrangement of which, as shown in Fig. 5465, enables the operator to measure off as much as 40 yds. a minute. The pointer e, set in motion by means of a pinion and toothed wheel, is arranged in such a manner that it may indicate one unit of measure after every two revolutions of the rollers D, D^1.

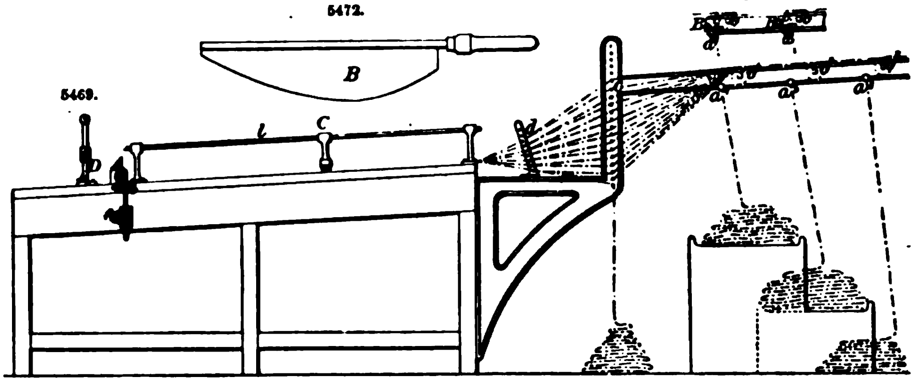
The finger bar E^1 is a wooden board of suitable dimensions fitted between the two side frames B, B, while the finger bar E forms portion of a boxing or casing, also made of wood, and so connected with the box or receptacle C that the stuff or fabric may be guided over it on its way to the rollers D, D^1. Inside this casing a right and left handed screw F is fitted between the side frames B, B, in appropriate bearings; the bosses of the two guide-pieces G, G, form the nuts of this screw, and in turning the latter by means of a small hand-wheel H the guide-pieces or arms G, G, will be either brought closer together or set farther apart, so as to become suited to the width of the stuff or fabric to be measured.

A graduated scale or gauge denoting the width of the fabric in inches, nails, centimètres, or other subdivisions of the unit of measure, is affixed to the top of the finger bar E, and the holes for the guide pins or pegs g, g, are at such distances from each other as will correspond to these subdivisions. The same graduated scale or gauge is reproduced on the cross bar I laid down in bearings i, i, connected with the framings B, B, and furnished with adjustable guide-pieces j, j, sliding thereupon, and fixed upon it by means of thumb-screws ʊ, ʊ, at distances equal to those at which the pins or pegs g, g, are set apart, so as to correspond to the width of the stuff or fabric and guide it in its course. The latter on leaving the rollers D, D^1, is guided over the finger bar E^1, fitted like E, and may continue its course over the cross bar I^1, arranged in a manner identical to I, that is to say, furnished with sliding pieces j^1, j^1, and thumb-screws $ʊ^1$, $ʊ^1$, and connected in any suitable manner with the roller on which the stuff or fabric is wound up or the board on which it is blocked.

Fig. 5469 is a side elevation, Fig. 5470 a plan, and Fig. 5471 an elevation of a machine for cutting and measuring cloth, for bags and for other purposes, invented by Chas. Blyth. The pieces of cloth intended to be operated upon are laid upon the floor or partly on a kind of shelf or stool with two or more surfaces, so as to economize space. The ends of the pieces are then carried over rods a, a^1, a^2, in this case, say of ⅜ in. diameter, to give the necessary amount of tension, and from thence round rollers b, b^1, b^2, to keep the edges in position. The pieces are then taken through or between round bars c, fitted in an upright bracket, and from thence through or between another set of

bars *d*, in one, two or several plys together, as may be most convenient. The whole number of plys are then assembled together or combined and led on to the table and drawn along until

5469. 5472. 5473



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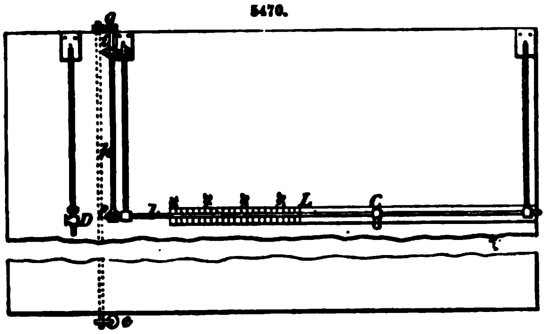

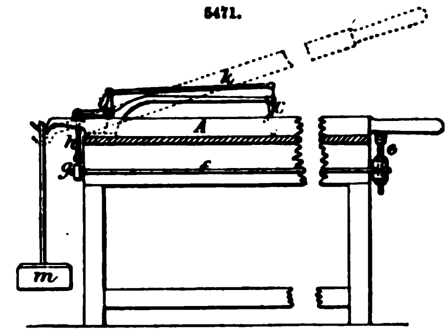

rather past the holding-down lever A, which is afterwards shut down on the cloth and held firmly in that position by means of the catch *e*. This holding-down lever A has a slot running along it of sufficient length to take the whole width of the cloth, and into this slot the knife B, Fig. 5472, is inserted, and is pushed under the lever towards the hinged end to give a fulcrum. It is then brought down until the whole width of the cloth is cut throughout the entire thickness of the numerous plys. The catch *e* is then opened, and as it is firmly fixed on the spindle *f* that spindle has a partial rotary motion imparted to it; to the end of the spindle *f* an arm *g* is fixed, which communicates motion to the rod *h*, the other end of which is attached to the bell-crank *i*; this in its turn transmits motion through the rod *k* to the pencil C; the point of the pencil rests upon the cloth, and being thus made to move in a line across the table marks the cloth at that spot, that mark is then drawn under the index finger or pointer D, the lever shut down, the catch put into position to hold down the lever, which operation as just explained causes the pencil to mark the cloth, the knife is inserted, and the cloth is cut to the length or gauge required for the purpose for which it is intended. By repeating this operation any number of lengths may be cut in succession. The mark on the cloth by means of the pencil may be adjusted to any required length by the following means;—A rod *l* is made of any required length, upon which the pencil holder may be traversed, means being provided to firmly fix it at any part of the length of the rod, this rod is carried by brackets at each end. A graduated scale L is let in the top of the table, by which any required length may be marked by adjusting the pencil over the required figure of that scale. The lever A is counterbalanced by the weight *m*; the finger or pointer D is hinged so as to yield to the cloth when held and drawn forward by the hands, but falls back to its proper position before the pencil mark is brought up to it.

MECHANICAL MOVEMENTS.

Those means by which motion is transmitted for mechanical purposes are known as mechanical movements.

Motion, in mechanics, may be simple or compound. Simple motions are,—those of straight translation, which, if of indefinite duration, must be reciprocating; simple rotation, which may be either continuous or reciprocating, and when reciprocating is called oscillating; helical, which, if of indefinite duration, must be reciprocating. Compound motions consist of combinations of any of the simple motions.

Perpetual motion is an incessant motion conceived to be attainable by a machine supplying its own motive forces independently of any action from without, or which has within itself the means, when once set in motion, of continuing its motion perpetually, or until worn out, without any new application of external force; also the machine itself by means of which it is attempted, or supposed possible, to produce such motion; an invention much sought after, but physically impossible.

Fig. 5474 is a simple pulley used for lifting weights. In this the power must be equal to the weight to obtain equilibrium.

Fig. 5475. In this the lower pulley is movable. One end of the rope being fixed, the other must move twice as fast as the weight, and a corresponding gain of power is consequently effected.

Fig. 5476. Blocks and tackle. The power obtained by this contrivance is calculated as follows;—Divide the weight by double the number of pulleys in the lower block; the quotient is the power required to balance the weight.

5482. 5481. 5479. 5480. 5478. 5477. 5476. 5474. 5475.

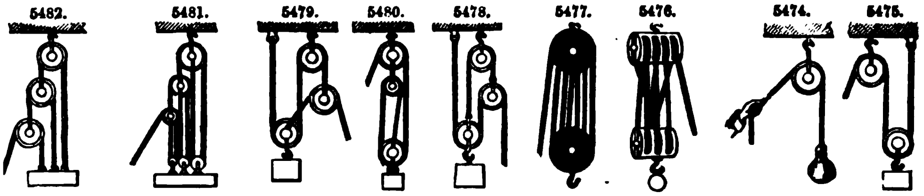

Fig. 5477 represents what are known as White's pulleys, which can either be made with separate loose pulleys, or a series of grooves can be cut in a solid block, the diameters being made in proportion to the speed of the rope; that is, 1, 3, and 5 for one block, and 2, 4, and 6 for the other. Power as 1 to 7.

Figs. 5478, 5479, are what are known as Spanish bartons.

Fig. 5480 is a combination of two fixed pulleys and one movable pulley.

Figs. 5481 to 5484 are different arrangements of pulleys. The following rule applies to these pulleys;—In a system of pulleys where each pulley is embraced by a cord attached at one end to a fixed point, and at the other to the centre of the movable pulley, the effect of the whole will be the number 2, multiplied by itself as many times as there are movable pulleys in the system.

5486. 5485. 5483. 5484.

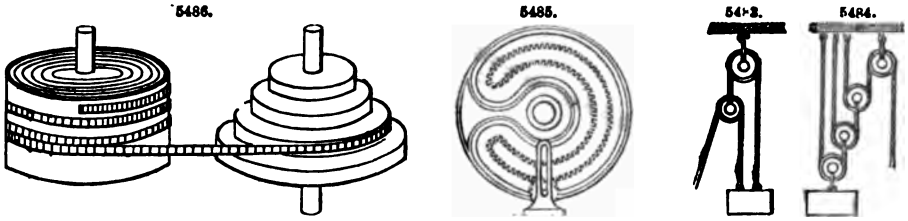

Fig. 5485. Mangle-wheel and pinion—so called from their application to mangles—converts continuous rotary motion of pinion into reciprocating rotary motion of wheel. The shaft of pinion has a vibratory motion, and works in a straight slot cut in the upright stationary bar to allow the pinion to rise and fall, and work inside and outside of the gearing of the wheel. The slot cut in the face of the mangle-wheel and following its outline is to receive and guide the pinion-shaft, and keep the pinion in gear.

Fig. 5486. Fusee-chain and spring-box, being the prime mover in some watches, particularly in those of English make. The fusee to the right is to compensate for the loss of force of the spring as it uncoils itself. The chain is on the small diameter of the fusee when the watch is wound up, as the spring has then the greatest force.

Fig. 5487. A frictional clutch-box, thrown in and out of gear by levers at the bottom. This is used for connecting and disconnecting heavy machinery. The eye of the disc to the right has a slot which slides upon a long key or feather fixed on the shaft.

Fig. 5488. Clutch-box. The pinion at the top gives a continuous rotary motion to the gear below, to which is attached half the clutch, and both turn loosely on the shaft. When it is desired to give motion to the shaft, the other part of the clutch, which slides upon a key or feather fixed in the shaft, is thrust into gear by the lever.

5490. 5489 5488. 5487.

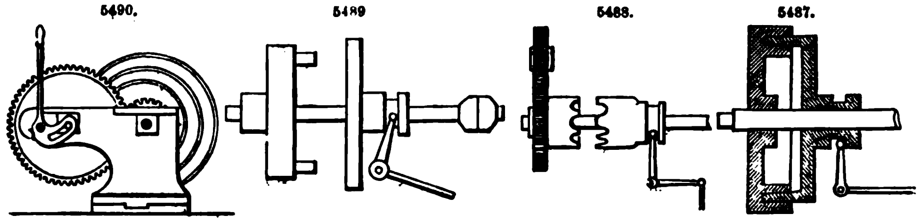

Fig. 5489. Another kind of clutch-box. The disc-wheel to the right has two holes corresponding to the studs fixed in the other disc; and being pressed against it, the studs enter the holes, when the two discs rotate together.

Fig. 5490. Used for throwing in and out of gear the speed motion on lathes. On depressing the lever, the shaft of the large wheel is drawn backward by reason of the slot in which it slides being cut eccentrically to the centre or fulcrum of the lever.

Fig. 5491 is a tilt-hammer motion, the revolution of the cam or wiper-wheel B lifting the hammer A four times in each revolution.

Fig. 5492. Intermittent alternating rectilinear motion is given to the rod A, by the continuous rotation of the shaft carrying the two cams or wipers, which act upon the projection B of the rod, and thereby lift it. The rod drops by its own weight. Used for ore-stampers or pulverizers, and for hammers.

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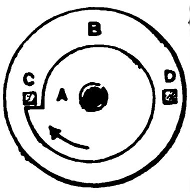

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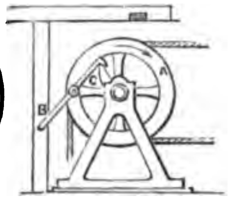

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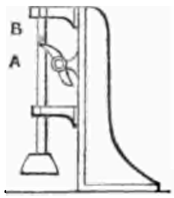

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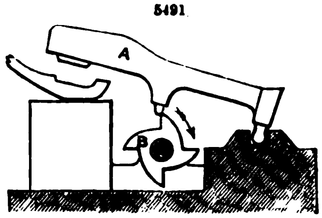

Fig. 5493. A method of working a reciprocating pump by rotary motion. A rope carrying one pump-rod is attached to the wheel A, which runs loosely upon the shaft. The shaft carries a cam C, and has a continuous rotary motion. At every revolution the cam seizes the hooked catch B, attached to the wheel, and drags it round, together with the wheel, and raises the rope until, on the extremity of the catch striking the stationary stop above, the catch is released, and the wheel is returned by the weight of the pump-bucket.

Fig. 5494. A contrivance for a self-reversing motion. The bevel-gear between the gears B and C is the driver. The gears B and C run loose upon the shaft, consequently motion is only communicated when one or other of them is engaged with the clutch-box D, which slides on a feather on the shaft, and is shown in gear with C. The wheel E, at the right, is driven by bevel-gearing from the shaft on which the gears B, C, and clutch are placed, and is about to strike the bell-crank G, and produce such a movement thereof as will cause the connecting rod to carry the weighted lever F beyond a perpendicular position, when the said lever will fall over suddenly to the left, and carry the clutch into gear with B, thereby reversing the motion of the shaft until the stud in the wheel E, coming round in the contrary direction, brings the weighted lever back past the perpendicular position, and again causes it to reverse the motion.

Fig. 5495. Continuous rotary converted into intermittent rotary motion. The disc-wheel B, carrying the stops C, D, turns on a centre eccentric to the cam A. On continuous rotary motion being given to the cam A, intermittent rotary motion is imparted to the wheel B, the stops free themselves from the offset of the cam at every half revolution, the wheel B remaining at rest until the cam has completed its revolution, when the same motion is repeated.

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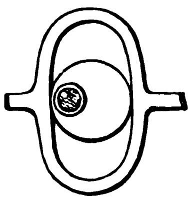

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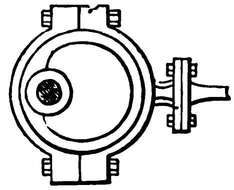

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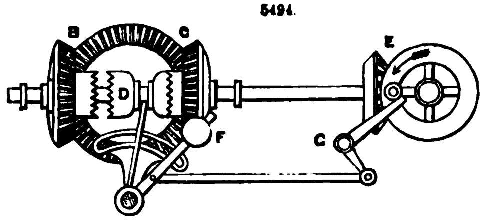

Fig. 5496. An eccentric generally used on the crank-shaft for communicating the reciprocating rectilinear motion to the valves of steam-engines, and sometimes used for pumping.

Fig. 5497. A modification of the above; an elongated yoke being substituted for the circular strap to obviate the necessity for any vibrating motion of the rod, which works in fixed guides.

Fig. 5498. Triangular eccentric, giving an intermittent reciprocating rectilinear motion, used in France for the valve-motion of steam-engines.

Fig. 5499. Ordinary crank-motion.

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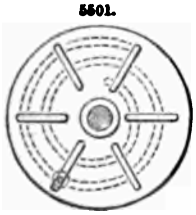

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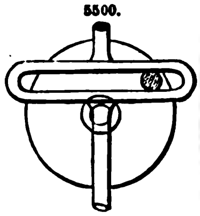

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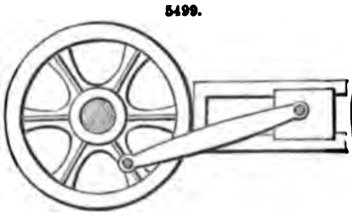

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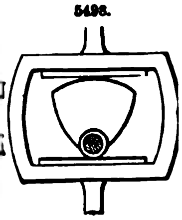

Fig. 5500. Crank-motion, with the crank-wrist working in a slotted yoke, thereby dispensing with the oscillating connecting-rod or pitman.

Fig. 5501. Variable crank, two circular plates revolving on the same centre. In one a spiral groove is cut; in the other a series of slots radiating from the centre. On turning one of these plates around its centre, the bolt shown near the bottom of the figure, and which passes through the spiral groove and radial slots, is caused to move toward or from the centre of the plates.

Fig. 5502. On rotating the upright shaft, reciprocating rectilinear motion is imparted by the oblique disc to the upright rod resting upon its surface.

Fig. 5503. A heart-cam. Uniform traversing motion is imparted to the horizontal bar by the rotation of the heart-shaped cam. The dotted lines show the mode of striking out the curve of the cam. The length of traverse is divided into any number of parts; and from the centre a series of concentric circles are described through these points. The outside circle is then divided into double the number of these divisions, and lines drawn to the centre. The curve is then drawn through the intersections of the concentric circles and the radiating lines.

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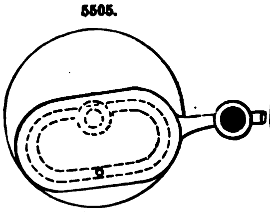

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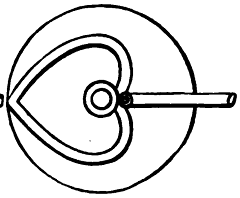

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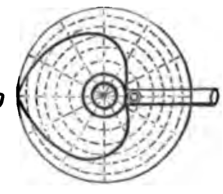

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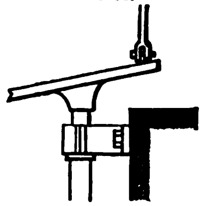

Fig. 5504. This is a heart-cam, similar to Fig. 5503, except that it is grooved.
Fig. 5505. Irregular vibrating motion is produced by the rotation of the circular disc, in which is fixed a crank-pin, working in an endless groove, cut in the vibrating arm.
Fig. 5506. Spiral guide attached to the face of a disc; used for the feed-motion of a drilling machine.
Fig. 5507. Quick return crank-motion, applicable to shaping machines.

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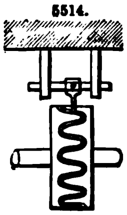

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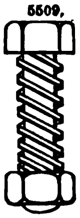

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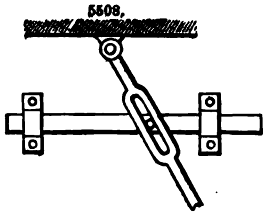

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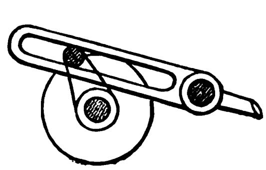

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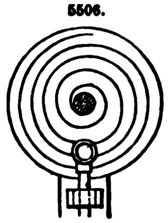

Fig. 5508. Rectilinear motion of horizontal bar, by means of vibrating slotted bar hung from the top.
Fig. 5509. Common screw bolt and nut; rectilinear motion obtained from circular motion.
Fig. 5510. Rectilinear motion of slide produced by the rotation of screw.
Fig. 5511. In this, rotary motion is imparted to the wheel by the rotation of the screw, or rectilinear motion of the slide by the rotation of the wheel. Used in screw-cutting and slide-lathes.
Fig. 5512. Screw stamping-press rectilinear motion from circular motion.

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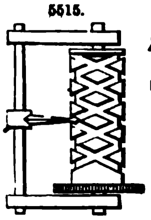

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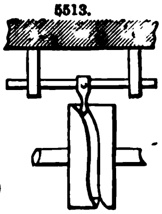

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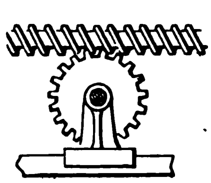

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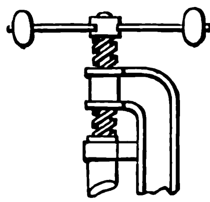

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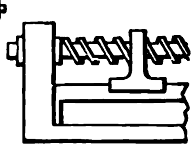

Figs. 5513, 5514. Uniform reciprocating rectilinear motion, produced by rotary motion of grooved cams.
Fig. 5515. Uniform reciprocating rectilinear motion from uniform rotary motion of a cylinder, in which are cut reverse threads or grooves, which necessarily intersect twice in every revolution. A point inserted in the groove will traverse the cylinder from end to end.
Fig. 5516. The rotation of the screw at the left-hand side produces a uniform rectilinear movement of a cutter, which cuts another screw-thread. The pitch of the screw to be cut may be varied by changing the sizes of the wheels at the end of the frame.
Fig. 5517. Uniform circular into uniform rectilinear motion; used in spooling frames for leading or guiding the thread on to the spools. The roller is divided into two parts, each having a fine screw-thread cut upon it, one a right and the other a left hand screw. The spindle, parallel with the roller, has arms which carry two half-nuts, fitted to the screws, one over and the other under the roller. When one half-nut is in, the other is out of gear. By pressing the lever to the right or left, the rod is made to traverse in either direction.
Fig. 5518. Micrometer screw. Great power can be obtained by this device. The threads are made of different pitch, and run in different directions; consequently a die or nut, fitted to the inner and smaller screw, would traverse only the length of the difference between the pitches for every revolution of the outside hollow screw in a nut.
Fig. 5519. Persian drill. The stock of the drill has a very quick thread cut upon it, and revolves freely, supported by the head at the top, which rests against the body. The button or nut,

shown on the middle of the screw, is held firm in the hand, and pulled quickly up and down the stock, thus causing it to revolve to the right and left alternately.

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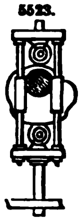

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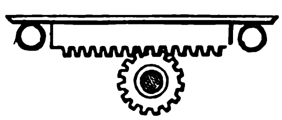

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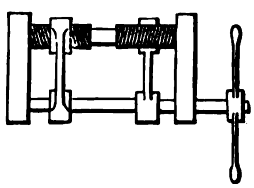

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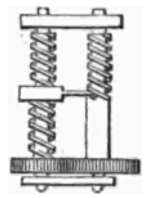

Fig. 5520. Circular into rectilinear motion, or the reverse, by means of rack and pinion.

Fig. 5521. Rotary motion of the toothed wheels produces rectilinear motion of the double rack, and gives equal force and velocity to each side, both wheels being of equal size.

Fig. 5522. A substitute for the crank. Reciprocating rectilinear motion of the frame carrying the double rack produces a uniform rotary motion of the pinion-shaft. A separate pinion is used for each rack, the two racks being in different planes. Both pinions are loose on the shaft. A ratchet-wheel is fast on the shaft outside of each pinion, and a pawl attached to the pinion to engage in it, one ratchet-wheel having its teeth set in one direction, and the other having its teeth set in the opposite direction. When the racks move one way, one pinion turns the shaft by means of its pawl and ratchet; and when the racks move the opposite way, the other pinion acts in the same way, one pinion always turning loosely on the shaft.

Fig. 5523. A cam acting between two friction-rollers in a yoke. Has been used to give the movement to the valve of a steam-engine.

Fig. 5524. A mode of doubling the length of stroke of a piston-rod, or the throw of a crank. A

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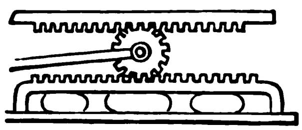

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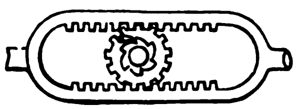

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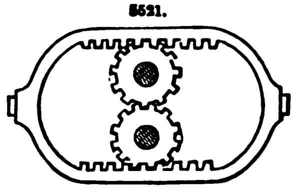

pinion revolving on a spindle attached to the connecting rod or pitman is in gear with a fixed rack. Another rack carried by a guide-rod above, and in gear with the opposite side of the pinion, is free to traverse backward and forward. Now, as the connecting rod communicates to the pinion the full length of stroke, it would cause the top rack to traverse the same distance, if the bottom rack was alike movable; but as the latter is fixed, the pinion is made to rotate, and consequently the top rack travels double the distance.

Fig. 5525. Reciprocating rectilinear motion of the bar carrying the oblong endless rack, produced by the uniform rotary motion of the pinion working alternately above and below the rack. The shaft of the pinion moves up and down in, and is guided by, the slotted bar.

Fig. 5526. Each jaw is attached to one of the two segments, one of which has teeth outside and the other teeth inside. On turning the shaft carrying the two pinions, one of which gears with one and the other with the other segment, the jaws are brought together with great force.

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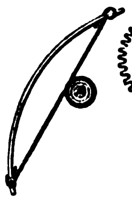

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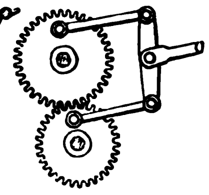

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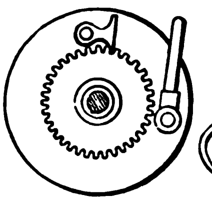

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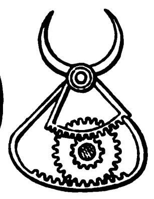

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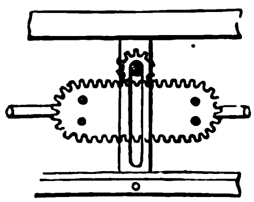

Fig. 5527. Alternating rectilinear motion of the rod attached to the disc-wheel produces an intermittent rotary motion of the cog-wheel by means of the click attached to the disc-wheel. This motion, which is reversible by throwing over the click, is used for the feed of planing machines and other tools.

Fig. 5528. The rotation of the two spur-gears, with crank-wrists attached, produces a variable alternating traverse of the horizontal bar.

Fig. 5529. Intended as a substitute for the crank. Reciprocating rectilinear motion of the double rack gives a continuous rotary motion to the centre gear. The teeth on the rack act upon those of the two semicircular toothed sectors, and the spur-gears attached to the sectors operate upon the centre gear. The two stops on the rack, shown by dotted lines, are caught by the curved piece on the centre gear, and lead the toothed sectors alternately into gear with the double rack.

Fig. 5530. Fiddle drill. Reciprocating rectilinear motion of the bow, the string of which passes around the pulley on the spindle carrying the drill, producing alternating rotary motion of the drill.

Fig. 5531. A modification of the motion shown in Fig. 5528, but of a more complex character.

Fig. 5532. A bell-crank lever, used for changing the direction of any force.

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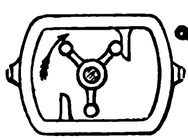

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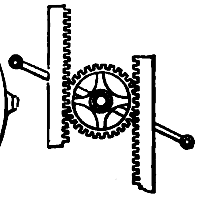

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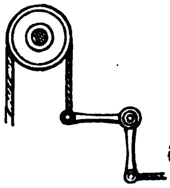

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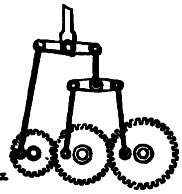

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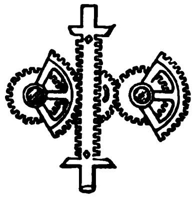

Fig. 5533. Motion used in air-pumps. On vibrating the lever fixed on the same shaft with the spur-gear, reciprocating rectilinear motion is imparted to the racks on each side, which are attached to the pistons of two pumps, one rack always ascending while the other is descending.

Fig. 5534. A continuous rotary motion of the shaft carrying the three wipers produces a reciprocating rectilinear motion of the rectangular frame. The shaft must revolve in the direction of the arrow for the parts to be in the position represented.

Fig. 5535. Chinese windlass. This embraces the same principles as the micrometer screw, Fig. 5516. The movement of the pulley in every revolution of the windlass is equal to half the difference between the larger and smaller circumferences of the windlass barrel.

Fig. 5536. Shears for cutting metal plates. The jaws are opened by the weight of the long arm of the upper one, and closed by the rotation of the cam.

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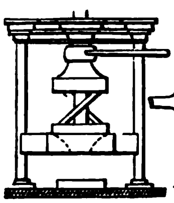

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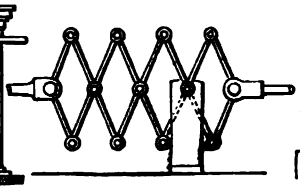

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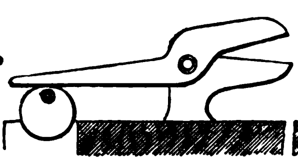

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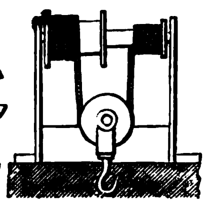

Fig. 5537. On rotating the disc carrying the crank-pin working in the slotted arm, reciprocating rectilinear motion is imparted to the rack at the bottom by the vibration of the toothed sector.

Fig. 5538. This is a motion which has been used in presses, to produce the necessary pressure upon the platen. Horizontal motion is given to the arm of the lever which turns the upper disc. Between the top and bottom discs are two bars which enter holes in the discs. These bars are in oblique positions, as shown in the drawing, when the press is not in operation; but when the top disc is made to rotate, the bars move toward perpendicular positions and force the lower disc down. The top disc must be firmly secured in a stationary position, except as to its revolution.

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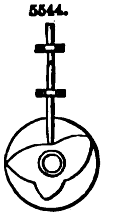

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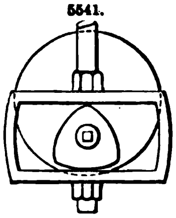

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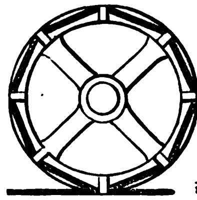

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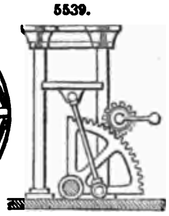

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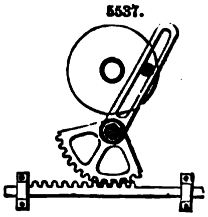

Fig. 5539. A simple press-motion is given through the hand-crank on the pinion-shaft, the pinion communicating motion to the toothed sector, which acts upon the platen, by means of the rod which connects it therewith.

Fig. 5540. Uniform circular motion into rectilinear, by means of a rope or band, which is wound several times around the drum.

Fig. 5541. Modification of the triangular eccentric, Fig. 5498, used on the steam-engine in the Paris Mint. The circular disc behind carries the triangular tappet, which communicates an alternate rectilinear motion to the valve-rod. The valve is at rest at the completion of each stroke for an instant, and is pushed quickly across the steam-ports to the end of the next.

Fig. 5542. A cam-wheel, of which a side view is shown, has its rim formed into teeth, or made of any profile form desired. The rod to the right is made to press constantly against the teeth or edge of the rim. On turning the wheel, alternate rectilinear motion is communicated to the rod. The character of this motion may be varied by altering the shape of the teeth, or profile of the edge, of the rim of the wheel.

Fig. 5543. Expansion eccentric, used in France to work the slide-valve of a steam-engine. The eccentric is fixed on the crank-shaft, and communicates motion to the forked vibrating arm, to the bottom of which the valve-rod is attached.

Fig. 5544. On turning the cam at the bottom a variable alternating rectilinear motion is imparted to the rod resting on it.

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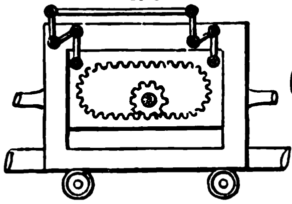

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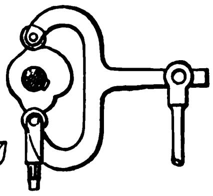

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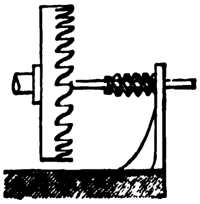

Fig. 5545. The internal rack, carried by the rectangular frame, is free to slide up and down within it for a certain distance, so that the pinion can gear with either side of the rack. Continuous circular motion of the pinion is made to produce reciprocating rectilinear motion of rectangular frame.

Fig. 5546. The toggle-joint arranged for a punching machine. Lever at the right is made to operate upon the joint of the toggle by means of the horizontal connecting link.

Fig. 5547. Endless-band saw. Continuous rotary motion of the pulleys is made to proudece continuous rectilinear motion of the straight parts of the saw.

Fig. 5548. Movement used for varying the length of the traversing guide-bar, which in silk machinery guides the silk on to spools or bobbins. The spur-gear, turning freely on its centre, is carried round by the larger circular disc, which turns on a fixed central stud, which has a pinion fast on its end. Upon the spur-gear is bolted a small crank, to which is jointed a connecting rod attached to traversing guide-bar. On turning the disc, the spur-gear is made to totate partly upon its centre by means of the fixed pinion, and consequently brings crank nearer to centre of disc. If the rotation of disc was continued, the spur-gear would make an entire revolution. During half a revolution the traverse would have been shortened a certain amount at every revolution of disc, according to the size of spur-gear; and during the other half it would have gradually lengthened in the same ratio.

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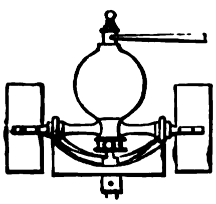

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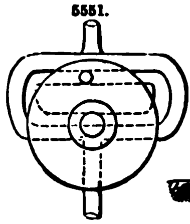

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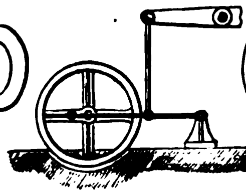

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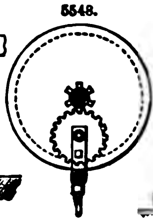

5546.

Fig. 5549. A system of crossed levers, termed lazy tongs. A short alternating rectilinear motion of rod at the right will give a similar but much greater motion to rod at the left. It is frequently used in children's toys. It has been applied in France to a machine for raising sunken vessels; also applied to ships' pumps three-quarters of a century ago.

Fig. 5550. Reciprocating curvilinear motion of the beam gives a continuous rotary motion to the crank and fly-wheel. The small standard at the right, to which is attached one end of the lever with which the beam is connected by the connecting rod, has a horizontal reciprocating rectilinear movement.

Fig. 5551. Continuous rotary motion of the disc produces reciprocating rectilinear motion of the yoke-bar, by means of the wrist or crank-pin on the disc working in the groove of the yoke. The groove may be so shaped as to obtain a uniform reciprocating rectilinear motion.

Fig. 5552. Steam-engine governor. The operation is as follows;—On engine starting, the spindle revolves and carries round the cross-head, to which fans are attached, and on which are also fitted two friction-rollers, which bear on two circular inclined planes attached securely to the centre shaft, the cross-head being loose on the shaft. The cross-head is made heavy or has a ball or other weight attached, and is driven by the circular inclined planes. As the speed of the centre shaft increases, the resistance of the air to the wings tends to retard the rotation of the cross-head; the friction-rollers, therefore, run up the inclined planes and raise the cross head, to the upper part of which is connected a lever operating upon the regulating valve of the engine.

Fig. 5553. Continuous circular motion of the spur-gears produces alternate circular motion of the crank attached to the larger gear.

Fig. 5554. Uniform circular converted, by the cams acting upon the levers, into alternating rectilinear motions of the attached rods.

Fig. 5555. A valve-motion for working steam expansively. The series of cams of varying throw are movable lengthwise of the shaft, so that either may be made to act upon the lever to which the valve-rod is connected. A greater or less movement of the valve is produced according as a cam of greater or less throw is opposite the lever.

Fig. 5556. An ellipsograph. The traverse bar, shown in an oblique position, carries two

studs which slide in the grooves of the cross-piece. By turning the traverse bar an attached pencil is made to describe an ellipse by the rectilinear movement of the studs in the grooves.

Fig. 5557. Circular motion into alternating rectilinear motion. The studs on the rotating disc strike the projection on the under side of the horizontal bar, moving it in one direction. The return motion is given by means of the bell-crank or elbow-lever, one arm of which is operated upon by the next stud, and the other strikes the stud on the front of the horizontal bar.

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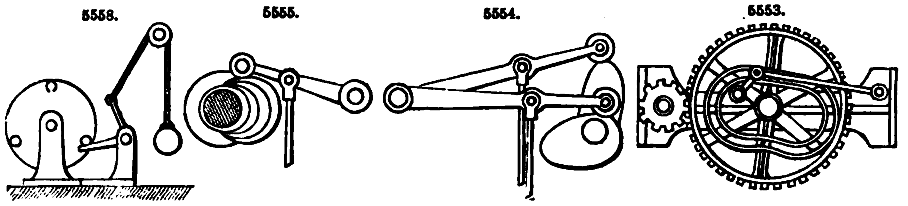

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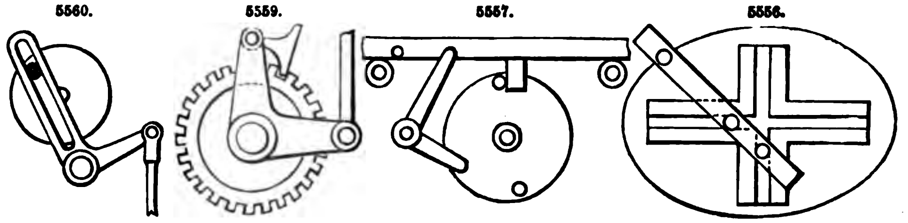

Fig. 5558. Circular motion into alternating rectilinear motion, by the action of the studs on the rotary disc upon one end of the bell-crank, the other end of which has attached to it a weighted cord passing over a pulley.

Fig. 5559. Reciprocating rectilinear motion into intermittent circular motion, by means of the pawl attached to the elbow-lever, and operating in the toothed wheel. Motion is given to the wheel in either direction according to the side on which the pawl works. This is used in giving the feed-motion to planing machines, and other tools.

Fig. 5560. Circular motion into variable alternating rectilinear motion, by the wrist or crank-pin on the rotating disc working in the slot of the bell-crank or elbow-lever.

Fig. 5561. A modification of the movement last described, a connecting rod being substituted for the slot in the bell-crank.

Fig. 5562. Reciprocating curvilinear motion of the treadle gives a circular motion to the disc. A crank may be substituted for the disc.

5564. 5563. 5562. 5561.

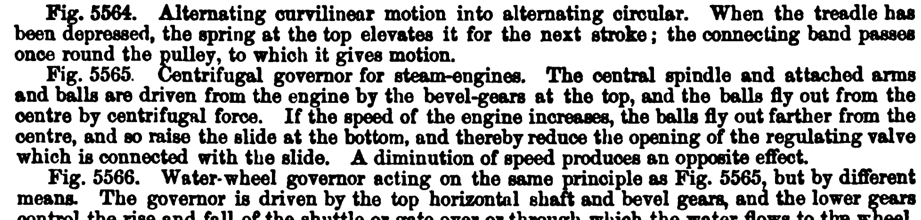

Fig. 5563. A modification of Fig. 5562, a cord and pulley being substituted for the connecting rod.

Fig. 5564. Alternating curvilinear motion into alternating circular. When the treadle has been depressed, the spring at the top elevates it for the next stroke; the connecting band passes once round the pulley, to which it gives motion.

Fig. 5565. Centrifugal governor for steam-engines. The central spindle and attached arms and balls are driven from the engine by the bevel-gears at the top, and the balls fly out from the centre by centrifugal force. If the speed of the engine increases, the balls fly out farther from the centre, and so raise the slide at the bottom, and thereby reduce the opening of the regulating valve which is connected with the slide. A diminution of speed produces an opposite effect.

Fig. 5566. Water-wheel governor acting on the same principle as Fig. 5565, but by different means. The governor is driven by the top horizontal shaft and bevel gears, and the lower gears control the rise and fall of the shuttle or gate over or through which the water flows to the wheel. The action is as follows;—The two bevel-gears on the lower part of the centre spindle, which are furnished with studs, are fitted loosely to the spindle, and remain at rest so long as the governor has a proper velocity; but immediately the velocity increases, the balls, flying farther out, draw up the pin which is attached to a loose sleeve which slides up and down the spindle, and this pin, coming in contact with the stud on the upper bevel-gear, causes that gear to rotate with the spindle, and to give motion to the lower horizontal shaft in such a direction as to make it raise the shuttle or gate, and so reduce the quantity of water passing to the wheel. On the contrary, if the speed of the governor decreases below that required, the pin falls and gives motion to the

lower bevel-gear, which drives the horizontal shaft in the opposite direction, and produces a contrary effect.

Fig. 5567. Another arrangement for a water-wheel governor. In this the governor controls the shuttle or gate by means of the cranked lever, which acts on the strap or belt in the following manner;—The belt runs on one of three pulleys, the middle one of which is loose on the governor spindle, and the upper and lower ones fast. When the governor is running at the proper speed the belt is on the loose pulley, as shown; but when the speed increases, the belt is thrown on the lower pulley, and thereby caused to act upon suitable gearing for raising the gate or shuttle and decreasing the supply of water. A reduction of the speed of the governor brings the belt on the upper pulley, which acts upon gearing for producing an opposite effect on the shuttle or gate.

5571. 5569. 5568. 5567. 5566. 5565.

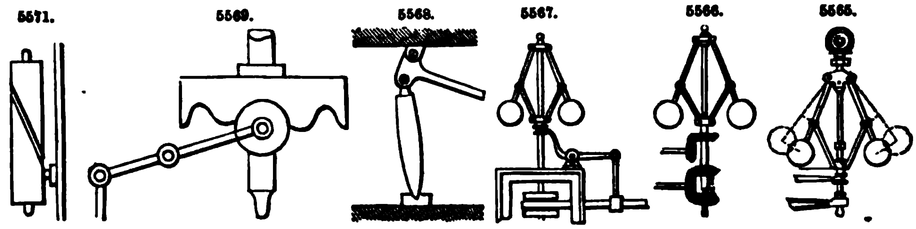

Fig. 5568. A knee-lever, differing slightly from the toggle-joint shown in Fig. 5546. It is often used for presses and stamps, as a great force can be obtained by it. The action is by raising or lowering the horizontal lever.

Fig. 5569. Circular into rectilinear motion. The waved wheel, or cam, on the upright shaft communicates a rectilinear motion to the upright bar through the oscillating rod.

Fig. 5570. The rotation of the disc carrying the crank-pin gives a to-and-fro motion to the connecting rod, and the slot allows the rod to remain at rest at the termination of each stroke. It has been used in a brick press, in which the connecting rod draws a mould backward and forward, and permits it to rest at the termination of each stroke, that the clay may be deposited in it and the brick extracted.

Fig. 5571. A drum, or cylinder, having an endless spiral groove extending all around it, one-half of the groove having its pitch in one, and the other half its pitch in the opposite direction. A stud on a reciprocating rectilinearly-moving rod works in the groove, and so converts reciprocating into rotary motion. This has been used as a substitute for the crank in a steam-engine, and as a means of transmitting motion in Foster's pressure gauge.

Fig. 5572. The slotted crank at the left hand of the figure is on the main shaft of an engine, and the pitman which connects it with the reciprocating moving power is furnished with a pin which works in the slot of the crank. Intermediate between the first crank and the moving power is a shaft carrying a second crank, of an invariable radius, connected with the same pitman. While the first crank moves in a circular orbit, the pin at the end of the pitman is compelled to move in an elliptical orbit, thus increasing the leverage of the main crank at those points which are most favourable for the transmission of power.

5574. 5573. 5572. 5570.

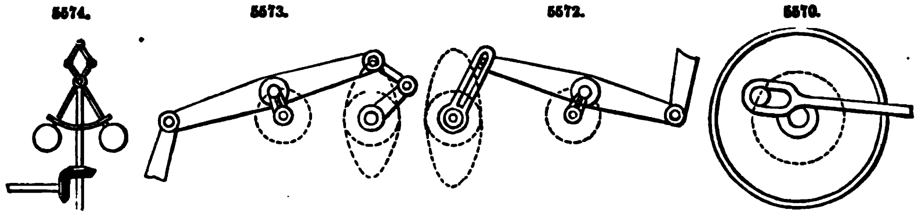

Fig. 5573. A modification of Fig. 5572, in which a link is used to connect the pitman with the main crank, thereby dispensing with the slot in the crank.

Fig. 5574. Another form of steam-engine governor. Instead of the arms being connected with a slide working on a spindle, they cross each other, and are elongated upward beyond the top, and connected with the valve-rod by two short links.

Fig. 5575. Valve-motion and reversing gear, used in oscillating marine engines. The two eccentric-rods give an oscillating motion to the slotted link, which works the curved slide over the trunnion. Within the slot in the curved slide is a pin attached to the arm of a rock-shaft, which gives motion to the valve. The curve of the slot in the slide is an arc of a circle, described from the centre of the trunnion, and as it moves with the cylinder it does not interfere with the stroke of the valve. The two eccentrics and links are like those of the link-motion used in locomotives.

Fig. 5576. A mode of obtaining an egg-shaped elliptical movement.

Fig. 5577. A movement used in silk machinery for the same purpose as that described in Fig. 5548. On the back of a disc or bevel-gear is secured a screw, with a tappet-wheel at one extremity. On each revolution of the disc the tappet-wheel comes in contact with a pin or tappet, and thus receives an intermittent rotary movement. A wrist, secured to a nut on the screw, enters and works in a slotted bar at the end of the rod, which guides the silk on the bobbins. Each revolution of the disc varies the length of stroke of the guide-rod, as the tappet-wheel on the end of the screw turns the screw with it, and the position of the nut on the screw is therefore changed.

Fig. 5578. Carpenters' bench-clamp. By pushing the clamp between the jaws they are made to turn on the screws and clamp the sides.

5578. 5577. 5576. 5575.

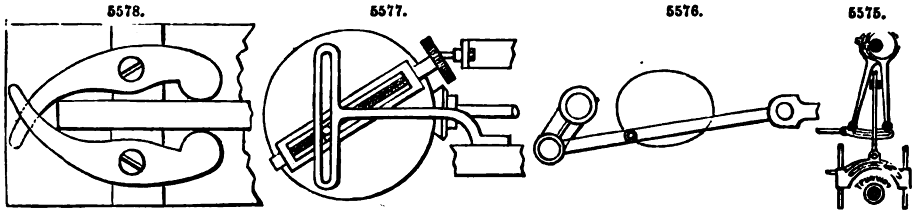

Fig. 5579. A means of giving one complete revolution to the crank of an engine to each stroke of the piston.

Figs. 5580, 5581. Contrivance for uncoupling engines. The wrist, which is fixed on one arm of the crank, not shown, will communicate motion to the arm of the crank which is represented, when the ring on the latter has its slot in the position shown in Fig. 5580. But when the ring is turned to bring the slot in the position shown in Fig. 5581, the wrist passes through the slot, without turning the crank to which the ring is attached.

Fig. 5582. Contrivance for varying the speed of the slide carrying the cutting tool in slotting and shaping machines. The driving shaft works through an opening in a fixed disc, in which is a circular slot. At the end of the shaft is a slotted crank. A slide fits in the slot of the crank and in the circular slot; and to the outward extremity of this slide is attached the connecting rod which works the slide carrying the cutting tool. When the driving shaft rotates, the crank is carried round, and the slide carrying the end of the connecting rod is guided by the circular slot, which is placed eccentrically to the shaft; therefore, as the slide approaches the bottom, the length of the crank is shortened, and the speed of the connecting rod is diminished.

5584. 5583. 5582. 5581. 5580. 5579.

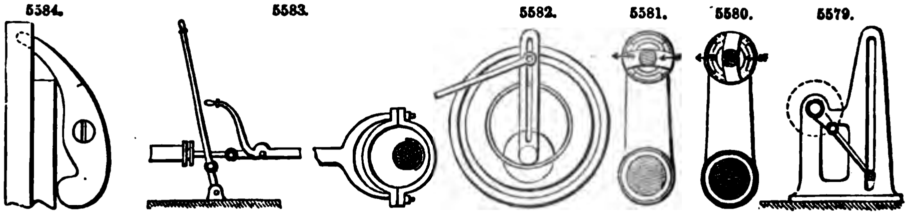

Fig. 5583. Reversing gear for a single engine. On raising the eccentric-rod the valve-spindle is released. The engine can then be reversed by working the upright lever, after which the eccentric-rod is let down again. The eccentric in this case is loose upon the shaft, and driven by a projection on the shaft acting upon a nearly semicircular projection on the side of the eccentric, which permits the eccentric to turn half-way round on the shaft on reversing the valves.

Fig. 5584. This only differs from Fig. 5578 in being composed of a single pivoted clamp operating in connection with a fixed side-piece.

Figs. 5585, 5586. Diagonal catch and hand-gear used in large blowing and pumping engines. In Fig. 5585 the lower steam-valve and upper eduction-valve are open, while the upper steam-valve and lower eduction-valve are shut; consequently the piston will be ascending. In the ascent of the piston-rod the lower handle will be struck by the projecting tappet, and being raised will become engaged by the catch, and shut the upper eduction and lower steam valves; at the same time the upper handle being disengaged from the catch, the back weight will pull the handle up and open the upper steam and lower eduction valves, when the piston will consequently descend. Fig. 5586 represents the position of the catches and handles when the piston is at the top of the cylinder. In going down, the tappet of the piston-rod strikes the upper handle, and throws the catches and handles to the position shown in Fig. 5585.

Figs. 5587, 5588, represent a modification of Figs. 5585, 5586, the diagonal catches being superseded by two quadrants.

5598. 5590. 5588. 5587. 5586. 5585.

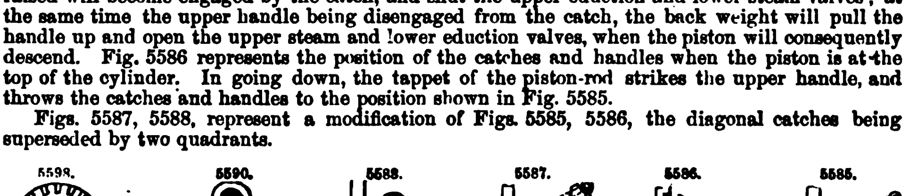

Fig. 5589. Link-motion valve-gear of a locomotive. Two eccentrics are used for one valve, one for the forward and the other for the backward movement of the engine. The extremities of the eccentric-rods are jointed to a curved slotted bar, or, as it is termed, a link, which can be raised or lowered by an arrangement of levers terminating in a handle as shown. In the slot of the link is a slide and pin connected with an arrangement of levers terminating at the valve-stem. The

link, in moving with the action of the eccentrics, carries with it the slide, and thence motion is communicated to the valve. Suppose the link raised, so that the slide is in the middle, then the link will oscillate on the pin of the slide, and consequently the valve will be at rest. If the link is moved so that the slide is at one of its extremities, the whole throw of the eccentric connected with that extremity will be given to it, and the valve and steam-ports will be opened to the full, and it will only be toward the end of the stroke that they will be totally shut; consequently the steam will have been admitted to the cylinder during almost the entire length of each stroke. But if the slide is between the middle and the extremity of the slot, as shown in the figure, it receives only a part of the throw of the eccentric, and the steam-ports will only be partially opened, and are quickly closed again, so that the admission of steam ceases some time before the termination of the stroke, and the steam is worked expansively. The nearer the slide is to the middle of the slot the greater will be the expansion, and *vice versâ*.

Fig. 5590. Apparatus for disengaging the eccentric-rod from the valve-gear. By pulling up the spring handle below until it catches in the notch *a*, the pin is disengaged from the gab in the eccentric-rod.

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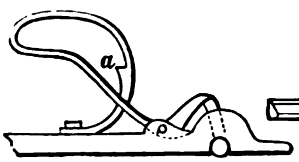

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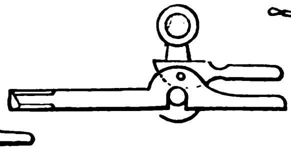

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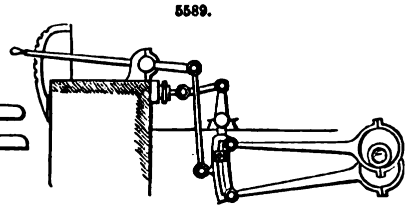


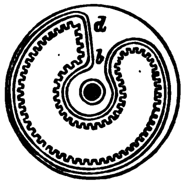
Figs. 5591, 5592. Modifications of Fig. 5590.

Fig. 5593. Another modification of Fig. 5590.

Fig. 5594. A screw-clamp. On turning the handle the screw thrusts upward against the holder, which, operating as a lever, holds down the piece of wood or other material placed under it on the other side of its fulcrum.

5596.

5595.



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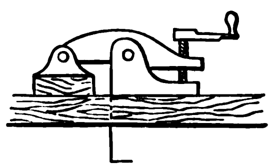

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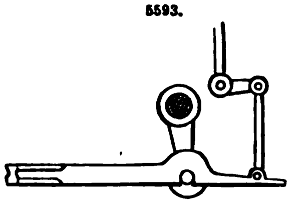
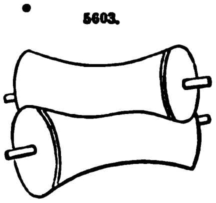


Fig. 5595. A variety of what is known as the mangle-wheel. One variety of this was illustrated by Fig. 5169. In this one the speed varies in every part of a revolution, the groove *b*, *d*, in which the pinion-shaft is guided, as well as the series of teeth, being eccentric to the axis of the wheel.

Fig. 5596. Another kind of mangle-wheel, with its pinion. With this as well as with that in the preceding figure, although the pinion continues to revolve in one direction, the mangle-wheel will make almost an entire revolution in one direction and the same in an opposite direction; but the revolution of the wheel in one direction will be slower than that in the other, owing to the greater radius of the outer circle of teeth.

Fig. 5597. Another mangle-wheel. In this the speed is equal in both directions of motion, only one circle of teeth being provided on the wheel. With all of these mangle-wheels the pinion-shaft is guided, and the pinion kept in gear, by a groove in the wheel. The said shaft is made with a universal joint, which allows a portion of it to have the vibratory motion necessary to keep the pinion in gear.

5603.



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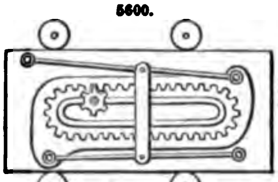

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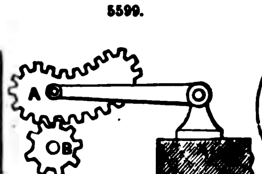

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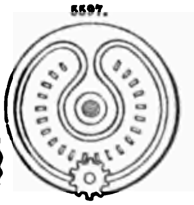


Fig. 5598. A mode of driving a pair of feed-rolls, the opposite surfaces of which require to move in the same direction. The two wheels are precisely similar, and both gear into the endless screw which is arranged between them. The teeth of one wheel only are visible, those of the other being on the back or side which is concealed from view.

Fig. 5599. The pinion B rotates about a fixed axis, and gives an irregular vibratory motion to the arm carrying the wheel A.

Fig. 5600. A modification of what is called a mangle-rack, Fig. 3211. In this the pinion

revolves, but does not rise and fall as in the former figure. The portion of the frame carrying the rack is jointed to the main portion of the frame by rods, so that when the pinion arrives at the end it lifts the rack by its own movement, and follows on the other side.

Fig. 5601. Another form of mangle-rack. The lantern-pinion revolves continuously in one direction, and gives reciprocating motion to the square frame, which is guided by rollers or grooves. The pinion has only teeth in less than half of its circumference, so that while it engages one side of the rack, the toothless half is directed against the other. The large tooth at the commencement of each rack is made to ensure the teeth of the pinion being properly in gear.

Fig. 5602. A regular vibrating movement of the curved slotted arm gives a variable vibration to the straight arm.

Fig. 5603. An illustration of the transmission of rotary motion from one shaft to another, arranged obliquely to it, by means of rolling contact.

5609. 5605. 5604. 5602. 5601.

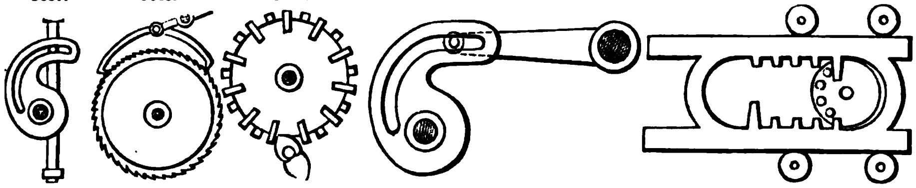


Fig. 5604 represents a wheel driven by a pinion of two teeth. The pinion consists in reality of two cams, which gear with two distinct series of teeth on opposite sides of the wheel, the teeth of one series alternating in position with those of the other.

Fig. 5605. A continuous circular movement of the ratchet-wheel, produced by the vibration of the lever carrying two pawls, one of which engages the ratchet-teeth in rising and the other in falling.

Fig. 5606. A modification of Fig. 5598, by means of two worms and worm-wheels.

Fig. 5607. A pin-wheel and slotted pinion, by which three changes of speed can be obtained. There are three circles of pins of equal distance on the face of the pin-wheel, and by shifting the slotted pinion along its shaft, to bring it in contact with one or the other of the circles of pins, a continuous rotary motion of the wheel is made, to produce three changes of speed of the pinion.

5612. 5611. 5608. 5607. 5606.

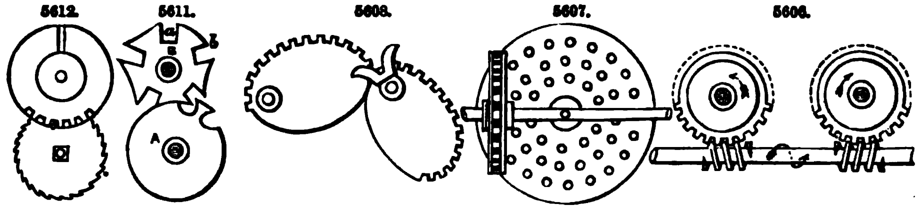


Fig. 5608 represents a mode of obtaining motion from rolling contact. The teeth are for making the motion continuous, or it would cease at the point of contact shown in the figure. The forked catch is to guide the teeth into proper contact.

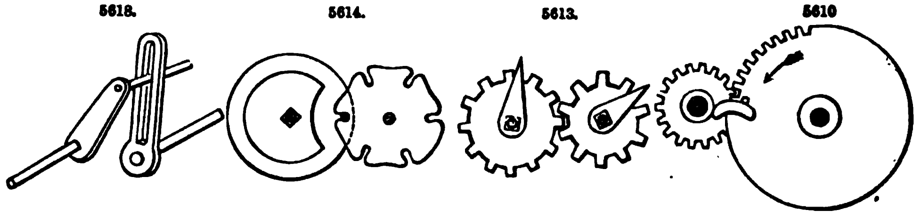
Fig. 5609. By turning the shaft carrying the curved slotted arm, a rectilinear motion of variable velocity is given to the variable bar.

Fig. 5610. A continuous rotary motion of the large wheel gives an intermittent rotary motion to the pinion-shaft. The part of the pinion shown next the wheel is cut of the same curve as the plain portion of the circumference of the wheel, and therefore serves as a lock while the wheel makes a part of a revolution, and until the pin upon the wheel strikes the guide-piece upon the pinion, when the pinion-shaft commences another revolution.

Fig. 5611. What is called the Geneva-stop, used in Swiss watches to limit the number of revolutions in winding-up; the convex curved part a, b, of the wheel B, serving as the stop.

Fig. 5612. Another kind of stop for the same purpose.

5615. 5614. 5613. 5610



Figs. 5613, 5614. Other modifications of the stop, the operations of which will be easily understood by comparison with Fig. 5611.

Fig. 5615. The external and internal mutilated cog-wheels work alternately into the pinion, and give slow forward and quick reverse motion.

Figs. 5616, 5617. These are parts of the same movement, which has been used for giving the roller motion in wool-combing machines. The roller to which wheel F, Fig. 5617, is secured, is required to make one-third of a revolution backward, then two-thirds of a revolution forward, when it must stop until another length of combed fibre is ready for delivery. This is accomplished by the grooved heart-cam C, D, B, *e*, Fig. 5616, the stud A working in the said groove; from C to D it moves the roller backward, and from D to *e* it moves it forward, the motion being transmitted through the catch G, to the notch-wheel F, on the roller-shaft H. When the stud A arrives at the point *e* in the cam, a projection at the back of the wheel which carries the cam strikes the projecting piece on the catch G, and raises it out of the notch in the wheel F, so that while the stud is travelling in the cam from *e* to C, the catch is passing over the plain surface between the two notches in the wheel F, without imparting any motion; but when stud A arrives at the part C, the catch has dropped in another notch and is again ready to move wheel F and roller as required.

Fig. 5618. The two crank-shafts are parallel in direction, but not in line with each other. The revolution of either will communicate motion to the other with a varying velocity, for the wrist of one crank working in the slot of the other is continually changing its distance from the shaft of the latter.

5626. 5621. 5619. 5617. 5616. 5615.

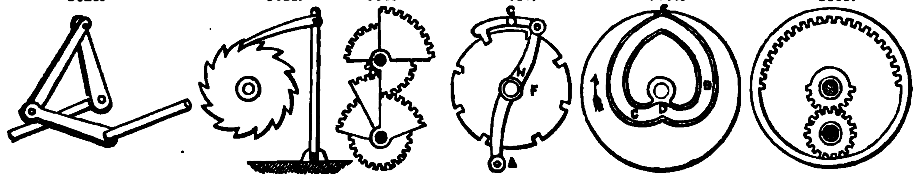


Fig. 5619. An arrangement for obtaining variable circular motion. The sectors are arranged on different planes, and the relative velocity changes according to the respective diameters of the sectors.

Fig. 5620. This represents an expanding pulley. On turning pinion *d* to the right or left, a similar motion is imparted to wheel *c*, which, by means of curved slots cut therein, thrusts the studs fastened to arms of pulley outward or inward, thus augmenting or diminishing the size of the pulley.

Fig. 5621. Intermittent circular motion of the ratchet-wheel from vibratory motion of the arm carrying a pawl.

Fig. 5622 represents a chain and chain pulley. The links being in different planes, spaces are left between them for the teeth of the pulley to enter.

5628. 5624. 5623. 5622. 5620.

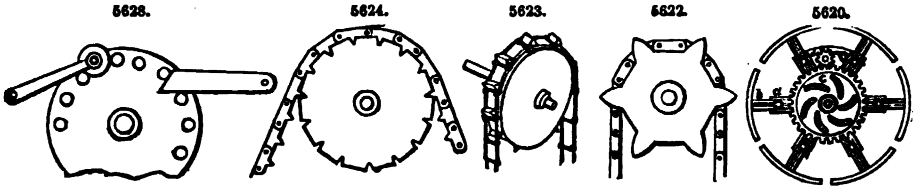


Fig. 5623. Another kind of chain and pulley.

Fig. 5624. Another variety.

Fig. 5625. Transmitted circular motion. The connecting rods are so arranged that when one pair of connected links is over the dead-point, or at the extremity of its stroke, the other is at right angles; continuous motion is thus ensured without a fly-wheel.

Fig. 5626. Drag-link motion. Circular motion is transmitted from one crank to the other.

Fig. 5627. Intermittent circular motion is imparted to the toothed wheel by vibrating the arm B. When the arm B is lifted, the pawl C is raised from between the teeth of the wheel, and travelling backward over the circumference again drops between two teeth on lowering the arm, and draws with it the wheel.

Fig. 5628 shows two different kinds of stops for a lantern-wheel.

5632. 5630. 5629. 5627. 5625.

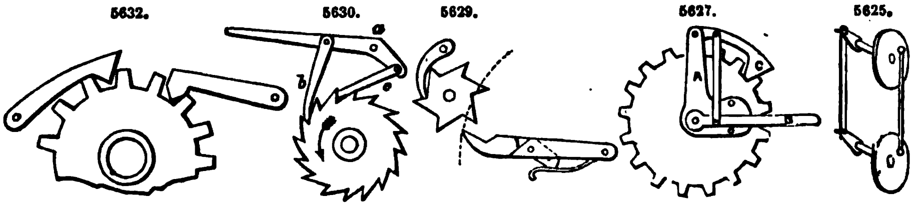


Fig. 5629. The oscillating of the tappet-arm produces an intermittent rotary motion of the ratchet-wheel. The small spring at the bottom of the tappet-arm keeps the tappet in the position shown in the drawing, as the arm rises, yet allows it to pass the teeth on the return motion.

Fig. 5630. A nearly continuous circular motion is imparted to the ratchet-wheel on vibrating the lever a, to which the two pawls b and c are attached.

Fig. 5631. A reciprocating circular motion of the top arm makes its attached pawl produce an intermittent circular motion of the crown-ratchet, or rag-wheel.

Fig. 5632. An arrangement of stops for a spur-gear.

Fig. 5633 represents varieties of stops for a ratchet-wheel.

5635. 5634. 5633. 5631.

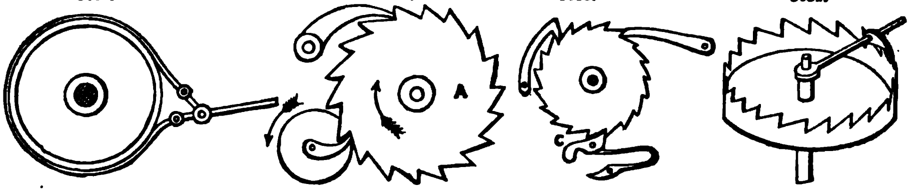


Fig. 5634. Intermittent circular motion is imparted to the wheel A by the continuous circular motion of the smaller wheel with one tooth.

Fig. 5635. A brake used in cranes and hoisting machines. By pulling down the end of the lever, the ends of the brake-strap are drawn toward each other, and the strap tightened on the brake-wheel.

Fig. 5636. A dynamometer, or instrument used for ascertaining the amount of useful effect given out by any motive power. It is used as follows;—A is a smoothly-turned pulley, secured on a shaft as near as possible to the motive power. Two blocks of wood are fitted to this pulley, or one block of wood and a series of straps fastened to a band or chain, as in the drawing, instead of a common block. The blocks, or block and straps, are so arranged that they may be made to bite or press upon the pulley by means of the screws and nuts on the top of the lever D. To estimate the amount of power transmitted through the shaft, it is only necessary to ascertain the amount of friction of the drum A when it is in motion, and the number of revolutions made. At the end of the lever D is hung a scale B, in which weights are placed. The two stops C, C′, are to maintain the lever as nearly as possible in a horizontal position. Now, suppose the shaft to be in motion, the screws are to be tightened and weights added in B, until the lever takes the position shown in the drawing, at the required number of revolutions. Therefore, the useful effect would be equal to the product of the weights, multiplied by the velocity at which the point of suspension of the weights would revolve if the lever were attached to the shaft.

Fig. 5637 represents a pantograph for copying, enlarging, and reducing plans. One arm is attached to and turns on the fixed point C. B is an ivory tracing point, and A the pencil. Arranged as shown, if we trace the lines of a plan with the point B, the pencil will reproduce it double the size. By shifting the slide attached to the fixed point C, and the slide carrying the pencil along their respective arms, the proportion to which the plan is traced will be varied.

5638. 5640. 5639. 5637. 5636.

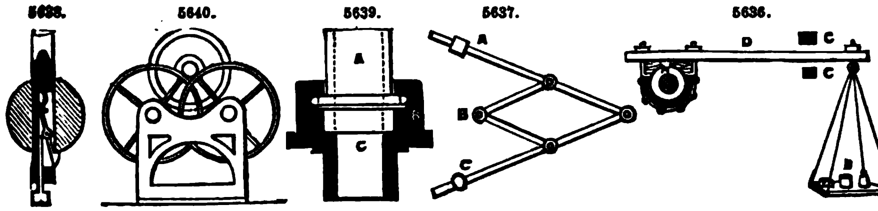


Fig. 5638. A mode of releasing a sounding weight. When the piece projecting from the bottom of the rod strikes the bottom of the sea, it is forced upward relatively to the rod, and withdraws the catch from under the weight, which drops off and allows the rod to be lifted without it.

Fig. 5639. Union coupling. A is a pipe, with a small flange abutting against the pipe C, with a screwed end; B, a nut which holds them together.

Fig. 5640. Anti-friction bearing. Instead of a shaft revolving in an ordinary bearing, it is sometimes supported on the circumference of wheels. The friction is thus reduced to the least amount.

Fig. 5641. Releasing hook used in pile-driving machines. When the weight W is sufficiently raised, the upper ends of the hooks A, by which it is suspended, are pressed inward by the sides of the slot B, in the top of the frame; the weight is thus suddenly released, and falls with accumulating force on to the pile-head.

Fig. 5642. A and B are two rollers, which require to be equally moved to and fro in the slot C. This is accomplished by moving the piece D, with oblique slotted arms, up and down.

Fig. 5643. Centrifugal check-hooks, for preventing accidents in case of the breakage of machinery, which raises and lowers workmen, or ores, in mines. A is a framework fixed to the side of the shaft of the mine, and having fixed studs D, attached. The drum on which the rope is wound is provided with a flange B, to which the check-hooks are attached. If the drum acquires a dangerously rapid motion, the hooks fly out by centrifugal force, and one or other, or all of them, catch hold of the studs D, and arrest the drum, and stop the descent of whatever is attached to the rope. The drum ought, besides this, to have a spring applied to it, otherwise the jerk arising from the sudden stoppage of the rope might produce worse effects than its rapid motion.

Fig. 5644. A sprocket-wheel to drive or to be driven by a chain.

Fig. 5645. A differential movement. The screw C works in a nut secured to the hub of the wheel E, the nut being free to turn in a bearing in the shorter standard, but prevented by the bearing from any lateral motion. The screw-shaft is secured in the wheel D. The driving shaft A carries two pinions F and B. If these pinions were of such size as to turn the two wheels D and E with an equal velocity, the screw would remain at rest; but the said wheels being driven at unequal velocities, the screw travels according to the difference of velocity.

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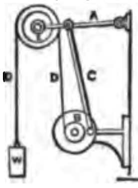
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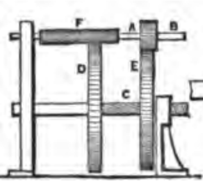
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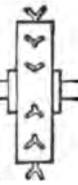
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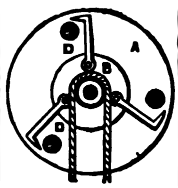
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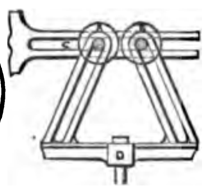
5641.


Fig. 5646. A combination movement, in which the weight W moves vertically with a reciprocating movement, the down-stroke being shorter than the up-stroke. B is a revolving disc, carrying a drum, which winds round itself the cord D. An arm C is jointed to the disc and to the upper arm A, so that when the disc revolves, the arm A moves up and down, vibrating on the point G. This arm carries with it the pulley E. Suppose we detach the cord from the drum and tie it to a fixed point, and then move the arm A up and down, the weight W will move the same distance, and in addition the movement given to it by the cord, that is to say, the movement will be doubled. Now, let us attach the cord to the drum, and revolve the disc B, and the weight will move vertically with the reciprocating motion, in which the down-stroke will be shorter than the up-stroke, because the drum is continually taking up the cord.

Figs. 5647, 5648. The first of these figures is an end view, and the second a side view, of an arrangement of mechanism for obtaining a series of changes of velocity and direction. D is a screw on which is placed eccentrically the cone B, and C is a friction-roller, which is pressed against the cone by a spring or weight. Continuous rotary motion, at a uniform velocity of the screw D carrying the eccentric cone, gives a series of changes of velocity and direction to the roller C. It will be understood that during every revolution of the cone the roller would press against a different part of the cone, and that it would describe thereon a spiral of the same pitch as the screw D. The roller C would receive a reciprocating motion, the movement in one direction being shorter than that in the other.

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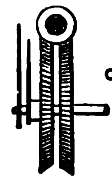
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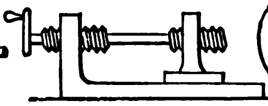
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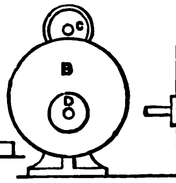
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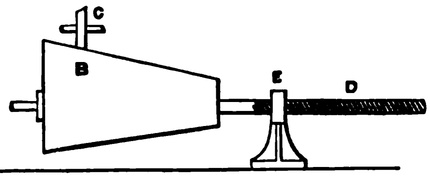

Fig. 5649. Two worm-wheels of equal diameter, but one having one tooth more than the other, both in gear with the same worm. Suppose the first wheel has 100 teeth and the second 101, one wheel will gain one revolution over the other during the passage of 100 × 101 teeth of either wheel across the plane of centres, or during 10,000 revolutions of the worm.

Fig. 5650. Variable motion. If the conical drum has a regular circular motion, and the friction-roller is made to traverse lengthwise, a variable rotary motion of the friction-roller will be obtained.

Fig. 5651. The shaft has two screws of different pitches cut on it, one screwing into a fixed bearing, and the other into a bearing free to move to and fro. Rotary motion of the shaft gives rectilinear motion to the movable bearing, a distance equal to the difference of pitches at each revolution.

Fig. 5652. 'Circular into reciprocating motion by means of a crank and oscillating rod.

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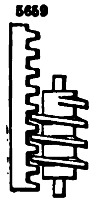
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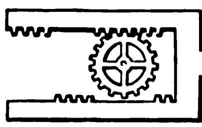
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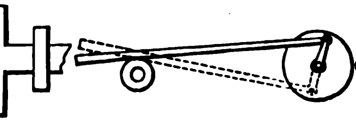
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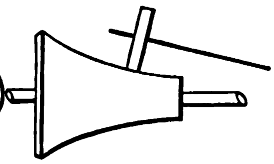

Fig. 5653. Continued rectilinear movement of the frame with mutilated racks, gives an alternate rotary motion to the spur-gear.

Fig. 5654. Anti-friction bearing for a pulley.

Fig. 5655. On vibrating the lever to which the two pawls are attached, a nearly continuous rectilinear motion is given to the ratchet-bar.

Fig. 5656. Rotary motion of the bevelled disc cam gives a reciprocating rectilinear motion to the rod bearing on its circumference.

5658. 5657. 5656. 5655. 5654.

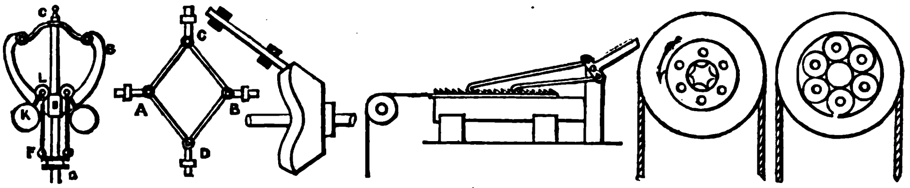

Fig. 5657. Rectilinear into rectilinear motion. When the rods A and B are brought together, the rods C and D are thrust farther apart, and the reverse.

Fig. 5658. An engine-governor. The rise and fall of the balls K are guided by the parabolic curved arms B, on which the anti-friction wheels L run. The rods F, connecting the wheels L with the sleeve, move it up and down the spindle C, D.

Fig. 5659. Rotary motion of the worm gives a rectilinear motion to the rack.

Fig. 5660. Continuous rotary motion of the cam gives a reciprocating rectilinear motion to the bar. The cam is of equal diameter in every direction measured across its centre.

Fig. 5661. Colt's invention for obtaining the movement of the cylinder of a revolving fire-arm by the act of cocking the hammer. As the hammer is drawn back to cock it, the dog *a*, attached to the tumbler, acts on the ratchet *b*, on the back of the cylinder. The dog is held up to the ratchet by a spring *c*.

5671. 5663. 5662. 5661. 5660

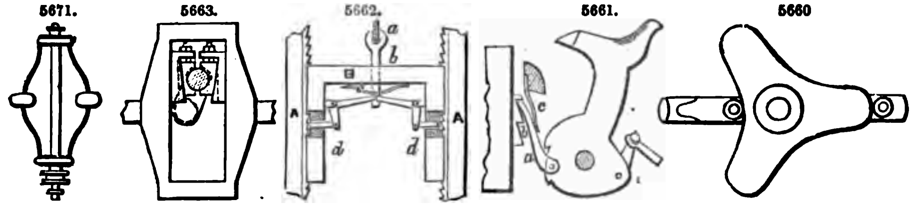

Fig. 5662. C. R. Otis's safety-stop for the platform of a hoisting apparatus. A are the stationary uprights, and B is the upper part of the platform working between them. The rope *a*, by which the platform is hoisted, is attached by a pin *b* and spring *c*, and the pin is connected by two elbow-levers with two pawls *d*, which work in ratchets secured to the uprights A. The weight of the platform and the tension of the rope, keep the pawls out of gear from the ratchets in hoisting or lowering the platform, but, in case of the breakage of rope, the spring *c* presses down the pin *b* and the attached ends of the levers, and so presses the pawls into the ratchets and stops the descent of the platform.

Fig. 5663. Crank and slotted cross-head, with Clayton's sliding journal-box applied to the crank-wrist. This box consists of two taper lining pieces and two taper jibs adjustable by screws, which serve at the same time to tighten the box on the wrist, and to set it out to the slot in the cross-head as the box and wrist wear.

Fig. 5664. A mode of working a windlass. By the alternating motion of the long hand-lever to the right, motion is communicated to the short lever, the end of which is in immediate contact with the rim of the wheel. The short lever has a very limited motion upon a pin, which is fixed in a block of cast iron, which is made with two jaws, each having a flange projecting inward in contact with the inner surface of the rim of the wheel. By the upward motion of the outward end of the short lever, the rim of the wheel is jammed between the end of the lever and the flanges of the block, so as to cause friction sufficient to turn the wheel by the further upward movement of the lever. The backward movement of the wheel is prevented by a common ratchet-wheel and pawls; as the short lever is pushed down it frees the wheel and slides freely over it.

Fig. 5665. The revolution of the disc causes the lever at the right to vibrate, by the pin moving in the groove in the face of the disc.

5668. 5667. 5666. 5665. 5664

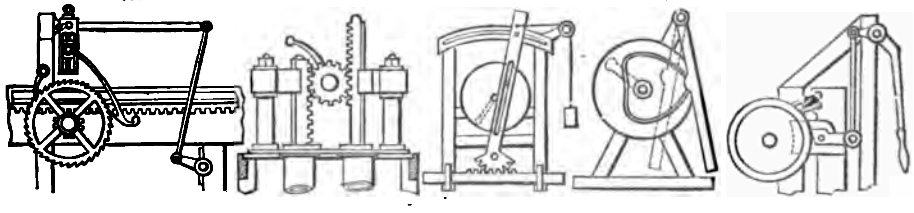

Fig. 5666. By the revolution of the disc, in which is fixed a pin working in a slot in the upright bar which turns on a centre near the bottom, both ends of the bar are made to traverse,

the toothed sector producing alternate rectilinear motion in the horizontal bar at the bottom, and also alternate perpendicular motion of the weight.

Fig. 5667. By a vibrating motion of the handle, motion is communicated by the pinion to the racks. This is used in working small air-pumps for scientific experiments.

Fig. 5668 represents a feeding apparatus for the bed of a sawing machine. By the revolution of the crank at the lower part of the figure, alternate motion is communicated to the horizontal arm of the bell-crank lever, whose fulcrum is at *a*, near the top left-hand corner of the figure. By this means, motion is communicated to the catch attached to the vertical arm of the lever, and the said catch communicates motion to the ratchet-wheel, upon the shaft of which is a toothed pinion, working in the rack attached to the side of the carriage. The feed is varied by a screw in the bell-crank lever.

Fig. 5669 is the movable head of a turning lathe. By turning the wheel to the right, motion is communicated to the screw, producing rectilinear motion of the spindle, in the end of which the centre is fixed.

Fig. 5670. Toe and lifter for working poppet-valves in steam-engines. The curved toe on the rock-shaft operates on the lifter attached to the lifting rod to raise the valve.

Fig. 5671. Pickering's governor. The balls are attached to springs, the upper end of each of which is attached to a collar fixed on the spindle, and the lower end to a collar on the sliding sleeve. The springs yield in a proper degree to the centrifugal force of the balls, and raise the sleeve; and as the centrifugal force diminishes, they draw the balls toward the spindle and depress the sleeve.

Fig. 5672. Conical pendulum, hung by a thin piece of round wire. Lower end connected with and driven in a circle by an arm attached to a vertical rotating spindle. The pendulum-rod describes a cone in its revolution.

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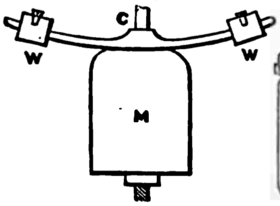

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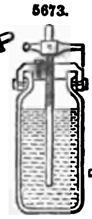

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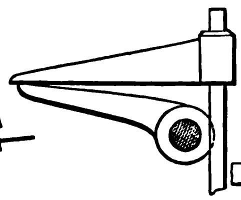

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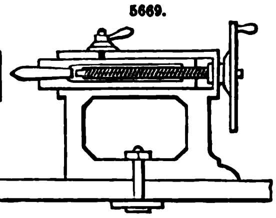

Fig. 5673. Mercurial compensation pendulum. A glass jar of mercury is used for the bob or weight. As the pendulum-rod is expanded lengthwise by increased temperature, the expansion of mercury in the jar carries it to a greater height therein, and so raises its centre of gravity relatively to the rod sufficiently to compensate for downward expansion of the rod. As rod is contracted by a reduction of temperature, contraction of mercury lowers it relatively to rod. In this way the centre of oscillation is always kept in the same place, and the effective length of pendulum always the same.

Fig. 5674. Compound bar compensation pendulum. C is a compound bar of brass and iron, or steel brazed together with brass downward. As brass expands more than iron, the bar will bend upward as it gets warmer, and carry the weights W, W, up with it, raising the centre of the aggregate weight M, to raise the centre of oscillation as much as elongation of the pendulum-rod would let it down.

Fig. 5675. Watch regulator. The balance-spring is attached at its outer end to a fixed stud R, and at its inner end to staff of balance. A neutral point is formed in the spring at P, by inserting it between two curb-pins in the lever, which is fitted to turn on a fixed ring concentric with staff of balance, and the spring only vibrates between this neutral point and staff of balance. By moving lever to the right, the curb-pins are made to reduce the length of acting part of spring, and the vibrations of balance are made faster, and by moving it to left an opposite effect is produced.

Fig. 5676. Compensation balance. *t*, *a*, *t'*, is the main bar of balance, with timing screws for regulation at the ends. *t* and *t'* are two compound bars, of which the outside is brass and the inside steel, carrying weights *b*, *b'*. As heat increases, these bars are bent inward by the greater expansion of the brass, and the weights are thus drawn inward, diminishing the inertia of the balance. As the heat diminishes, an opposite effect is produced. This balance compensates both for its own expansion and contraction, and that of the balance-spring.

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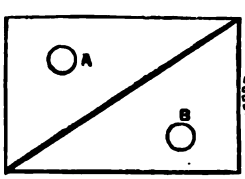

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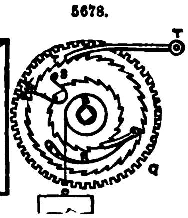

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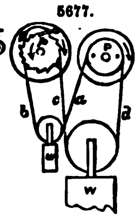

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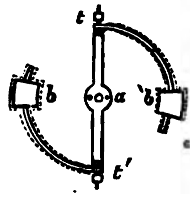

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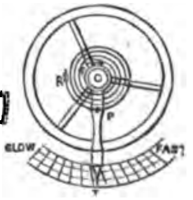

Fig. 5677. Endless chain, maintaining power on going barrel, to keep a clock going while winding, during which operation the action of the weight or main-spring is taken off the barrel. The wheel to the right is the going wheel, and that to the left the striking wheel. P is a

pulley fixed to the great wheel of the going part, and roughened, to prevent a rope or chain hung over it from slipping. A similar pulley rides on another arbor *p*, which may be the arbor of the great wheel of the striking part, and attached by a ratchet and click to that wheel, or to clock frame, if there is no striking part. The weights are hung, as may be seen, the small one being only large enough to keep the rope or chain on the pulleys. If the part *b* of the rope or chain is pulled down, the ratchet-pulley runs under the click, and the great weight is pulled up by *a*, without taking its pressure off the going wheel at all.

Fig. 5678. Harrison's going barrel. Larger ratchet-wheel, to which the click R is attached, is connected with the great wheel G by a spring S, S'. While the clock is going the weight acts upon the great wheel G, through the spring; but as soon as the weight is taken off by winding, the click T, whose pivot is set in the frame, prevents the larger ratchet from falling back, and so the spring S, S', still drives the great wheel during the time the clock takes to wind, as it need only just keep the escapement going, the pendulum taking care of itself for that short time. Good watches have a substantially similar apparatus.

Fig. 5679. A very convenient construction of parallel ruler for drawing, made by cutting a quadrangle through the diagonal, forming two right-angle triangles, A and B. It is used by sliding the hypothenuse of one triangle upon that of the other.

Fig. 5680. Parallel ruler, consisting of a simple straight ruler B, with an attached axle C, and pair of wheels A, A. The wheels, which protrude but slightly through the under side of the ruler, have their edges nicked to take hold of the paper and keep the ruler always parallel with any lines drawn upon it.

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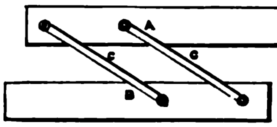

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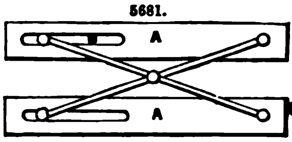

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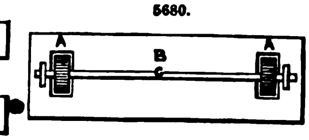

Fig. 5681. Compound parallel ruler, composed of two simple rulers A, A, connected by two crossed arms pivoted together at the middle of their length, each pivoted at one end to one of the rulers, and connected with the other one by a slot and sliding pin, as shown at B. In this the ends as well as the edges are kept parallel. The principle of construction of the several rulers represented is taken advantage of in the formation of some parts of machinery.

Fig. 5682. Parallel ruler composed of two simple rulers A, B, connected by two pivoted swinging arms C, C.

Fig. 5683. A simple means of guiding or obtaining a parallel motion of the piston-rod of an engine. The slide *a* moves in and is guided by the vertical slot in the frame, which is planed to a true surface.

Fig. 5684 differs from Fig. 5683 in having rollers substituted for the slides on the cross-head, said rollers working against straight guide-bars *a*, *a*, attached to the frame. This is used for small engines in France.

Fig. 5685. A parallel motion invented by Dr. Cartwright in the year 1787. The toothed wheels C, C, have equal diameters and numbers of teeth, and the cranks *a*, *a*, have equal radii, and are set in opposite directions, and consequently give an equal obliquity to the connecting rods during the revolution of the wheels. The cross-head on the piston-rod being attached to the two connecting rods, the piston-rod is caused to move in a right line.

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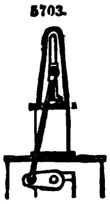

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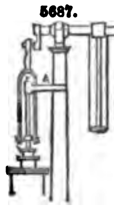

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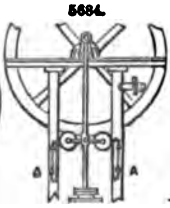

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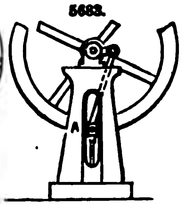


Fig. 5686. A piston-rod guide. The piston-rod A is connected with a wrist attached to a cog-wheel B, which turns on a crank-pin, carried by a plate C, which is fast on the shaft. The wheel B revolves around a stationary internally-toothed gear D, of double the diameter of B, and so motion is given to the crank-pin, and the piston-rod is kept upright.

Fig. 5687. The piston-rod is prolonged and works in a guide A, which is in line with the centre of the cylinder. The lower part of the connecting rod is forked to permit the upper part of the piston-rod to pass between.

Fig. 5688. An engine with crank-motion like that represented in Fig. 5490 and Fig. 5663, the crank-wrist journal working in a slotted cross-head A. This cross-head works between the pillar-guides D, D, of the engine framing.

Fig. 5689. A parallel motion used for the piston-rod of side-lever marine engines. F, C, is the radius bar, and E the cross-head to which the parallel bar E, D, is attached.

Fig. 5690. A parallel motion used only in particular cases.

Fig. 5691 shows a parallel motion used in some of the old single-acting beam-engines. The piston-rod is formed with a straight rack gearing with a toothed segment on the beam. The back of the rack works against a roller A.

Fig. 5692. A parallel motion commonly used for stationary beam-engines.

Fig. 5693. An arrangement of parallel motion for side-lever marine engines. The parallel rods connected with the side rods from the beams or side levers are also connected with short radius arms on a rack-shaft working in fixed bearings.

5693. 5691. 5690. 5689. 5688

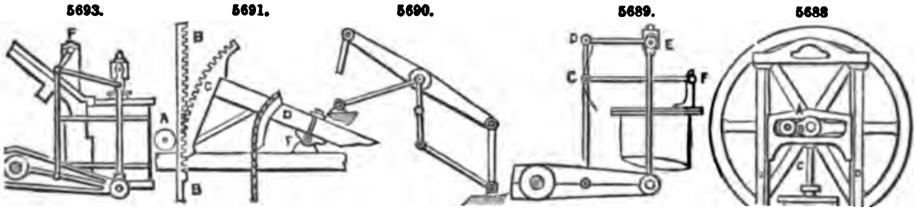


Fig. 5694. Parallel motion in which the radius rod is connected with the lower end of a short vibrating rod, the upper end of which is connected with the beam, and to the centre of which the piston-rod is connected.

Fig. 5695. Another modification, in which the radius bar is placed above the beam.

Fig. 5696. Parallel motion for direct-action engines. In this, the end of the bar B, C, is connected with the piston-rod, and the end B slides in a fixed slot D. The radius bar F, A, is connected at F with a fixed pivot, and at A midway between the ends of B, C.

5698. 5697. 5705. 5696. 5692.

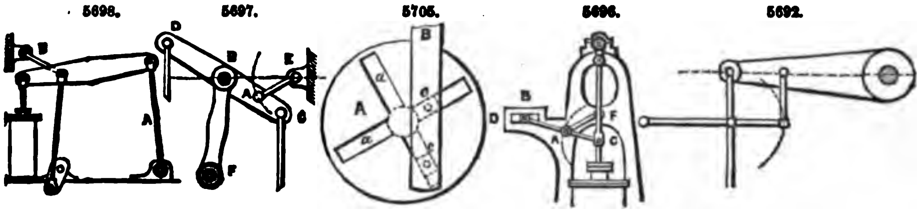


Fig. 5697. Another parallel motion. Beam D, C, with joggling pillar-support B, F, which vibrates from the centre F. The piston-rod is connected at C. The radius bar E, A, produces the parallel motion.

Fig. 5698. Grasshopper beam-engine. The beam is attached at one end to a rocking pillar A, and the shaft arranged as near to the cylinder as the crank will work. A is the radius bar of the parallel motion.

Fig. 5699. Old-fashioned single-acting beam pumping engine on the atmospheric principle, with chain connection between piston-rod and a segment at end of beam. The cylinder is open at top. Very low pressure steam is admitted below piston, and the weight of pump-rod and connections at the other end of beam helps to raise piston. Steam is then condensed by injection, and a vacuum thus produced below piston, which is then forced down by atmospheric pressure, thereby drawing up pump-rod.

Fig. 5700. Parallel motion for upright engine. A, A, are radius rods connected at one end with the framing, and at the other with a vibrating piece on top of piston-rod.

5703. 5702. 5701. 5700. 5699. 5695.

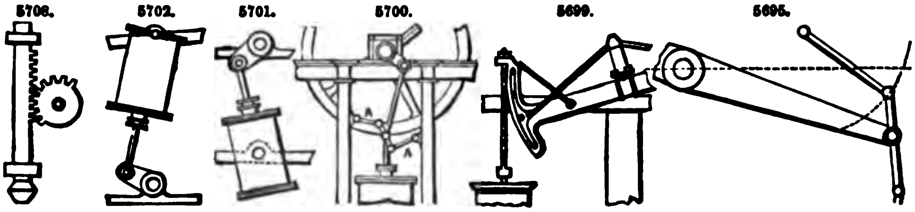


Fig. 5701. Oscillating engine. The cylinder has trunnions at the middle of its length working in fixed bearings, and the piston-rod is connected directly with the crank, and no guides are used.

Fig. 5702. Inverted oscillating or pendulum engine. The cylinder has trunnions at its upper end, and swings like a pendulum. The crank-shaft is below, and the piston-rod connected directly with crank.

Fig. 5703. Table-engine. The cylinder is fixed on a table-like base. The piston-rod has a cross-head working in straight slotted guides fixed on top of cylinder, and is connected by two side connecting rods with two parallel cranks on shaft under the table.

Fig. 5704. Section of disc-engine. Disc-piston, seen edgewise, has a motion substantially like a coin when it first falls after being spun in the air. The cylinder-heads are cones. The piston-rod is made with a ball to which the disc is attached, said ball working in concentric seats in cylinder-heads, and the left-hand end is attached to the crank-arm or fly-wheel on end of shaft at left. Steam is admitted alternately on either side of piston.

Fig. 5705. Mode of obtaining two reciprocating movements of a rod by one revolution of a shaft, patented in 1886 by B. F. Snyder, has been used for operating the needle of a sewing machine, by J. S. McCurday, also for driving a gang of saws. The disc A on the central rotating shaft has

two slots *a*, *a*, crossing each other at a right angle in the centre, and the connecting rod B has attached to it two pivoted slides *c*, *c*, one working in each slot.

Fig. 5706. Another form of parallel ruler. The arms are jointed in the middle and connected with an intermediate bar, by which means the ends of the ruler, as well as the sides, are kept parallel.

5710. 5694. 5707. 5706.

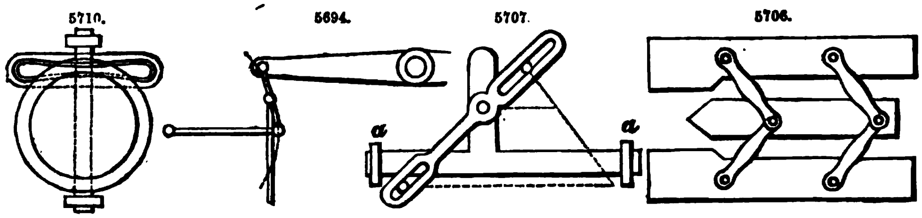


Fig. 5707. Traverse, or to-and-fro motion. The pin in the upper slot being stationary, and the one in the lower slot made to move in the direction of the horizontal dotted line, the lever will by its connection with the bar give to the latter a traversing motion in its guides *a*, *a*.

Fig. 5708. Stamp. Vertical percussive falls derived from horizontal rotating shaft. The mutilated tooth-pinion acts upon the rack to raise the rod until its teeth leave the rack and allow the rod to fall.

Fig. 5709. Another arrangement of the Chinese windlass, illustrated by Fig. 5535.

Fig. 5710. A modification of the crank and slotted cross-head, Fig. 5500. The cross-head contains an endless groove, in which the crank-wrist works, and which is formed to produce a uniform velocity of movement of the wrist or reciprocating rod.

Fig. 5711. The gyroscope, or rotascope, an instrument illustrating the tendency of rotating bodies to preserve their plane of rotation. The spindle of the metallic disc C is fitted to return easily in bearings in the ring A. If the disc is set in rapid rotary motion on its axis, and the pintle F at one side of the ring A is placed on the bearing in the top of the pillar G, the disc and ring seem indifferent to gravity, and instead of dropping begin to revolve about the vertical axis.

Fig. 5712. Bohnenberger's machine, illustrating the same tendency of rotating bodies. This consists of three rings, A, A^1, A^2, placed one within the other, and connected by pivots at right angles to each other. The smallest ring A^2 contains the bearings for the axis of a heavy ball B. The ball being set in rapid rotation, its axis will continue in the same direction, no matter how the position of the rings may be altered; and the ring A^2 which supports it will resist a considerable pressure tending to displace it.

5715. 5713. 5712. 5711. 5709. 5704

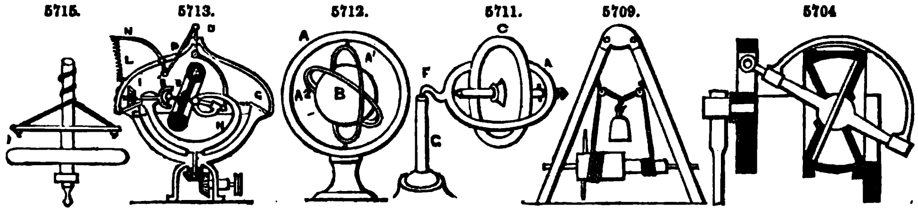


Fig. 5713. What is called the gyroscope governor, for steam-engines, introduced by Alban Anderson, in 1858. A is a heavy wheel, the axle B, B^1, of which is made in two pieces connected together by a universal joint. The wheel A is on one piece, B, and a pinion I on the other piece, B^1. The piece B is connected at its middle by a hinge-joint with the revolving frame H, so that variations in the inclination of the wheel A will cause the outer end of the piece B to rise and fall. The frame H is driven by bevel-gearing from the engine, and by that means the pinion I is carried round the stationary toothed circle G, and the wheel A is thus made to receive a rapid rotary motion on its axis. When the frame H and wheel A are in motion, the tendency of the wheel A is to assume a vertical position, but this tendency is opposed by a spring L. The greater velocity of the governor, the stronger is the tendency above mentioned, and the more it overcomes the force of the spring, and the reverse. The piece B is connected with the valve-rods by rods C, D, and the spring L is connected with the said rod by levers N and rod P.

Fig. 5714. Traverse of carriage, made variable by fusee, according to the variation in diameter where the band acts.

Fig. 5715. Primitive drilling apparatus. Being once set in motion, it is kept going by hand, by alternately pressing down and relieving the transverse bar to which the bands are attached, causing the bands to wind upon the spindle alternately in opposite directions, while the heavy disc or fly-wheel gives a steady momentum to the drill-spindle in its rotary motion.

Fig. 5716. Continuous rotary motion from oscillating. The beam being made to vibrate, the drum to which the cord is attached, working loose on fly-wheel shaft, gives motion to said shaft through the pawl and ratchet-wheel, the pawl being attached to drum and the ratchet-wheel fast on shaft.

Fig. 5717. Another simple form of clutch for pulleys, consisting of a pin on the lower shaft and a pin on side of pulley. The pulley is moved lengthwise of the shaft by means of a lever or other means, to bring its pin into or out of contact with the pin on shaft.

Fig. 5718. Alternating traverse of upper shaft and its drum, produced by pin on the end of the shaft working in oblique groove in the lower cylinder.

Fig. 5719. See-saw, one of the simplest illustrations of a limited oscillating or alternate circular motion.

5721. 5719. 5718. 5717. 5716. 5714.

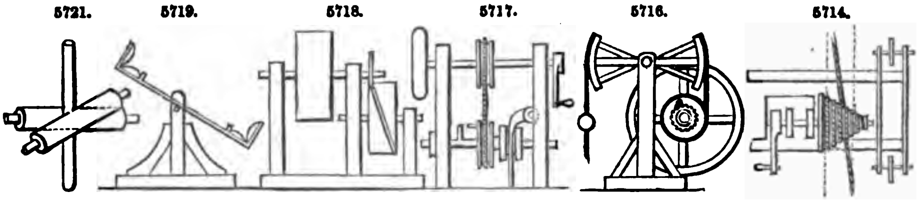


Fig. 5720. Intermittent rotary motion from continuous rotary motion about an axis at right angles. Small wheel on left is driver; and the friction-rollers on its radial studs work against the faces of oblique grooves or projections across the face of the larger wheel, and impart motion thereto.

Fig. 5721. Cylindrical rod arranged between two rollers, the axes of which are oblique to each other. The rotation of the rollers produces both a longitudinal and a rotary motion of the rod.

Fig. 5722. Drilling machine. By the large bevel-gear rotary motion is given to vertical drill shaft, which slides through small bevel-gear but is made to turn with it by a feather and groove, and is depressed by treadle connected with upper lever.

5740. 5722. 5723. 5720.

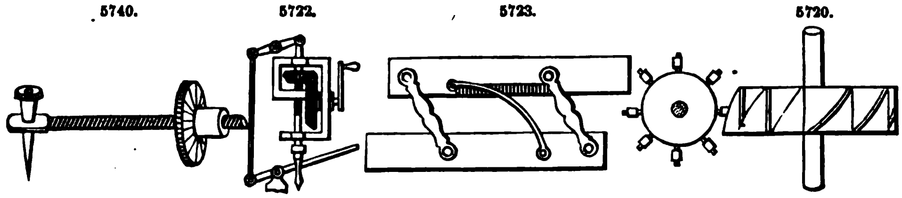


Fig. 5723. A parallel ruler with which lines may be drawn at required distances apart without setting out. Lower edge of upper blade has a graduated ivory scale, on which the incidence of the outer edge of the brass arc indicates the width between the blades.

Fig. 5724. Describing spiral line on a cylinder. The spur-gear which drives the bevel-gears, and thus gives rotary motion to the cylinder, also gears into the toothed rack, and thereby causes the marking point to traverse from end to end of the cylinder.

Fig. 5725. Cycloidal surfaces, causing pendulum to move in cycloidal curve, rendering oscillations isochronous, or equal-timed.

Fig. 5726. Motion for polishing mirrors, the rubbing of which should be varied as much as practicable. The handle turns the crank to which the long bar and attached ratchet-wheel are connected. The mirror is secured rigidly to the ratchet-wheel. The long bar, which is guided by pins in the lower rail, has both a longitudinal and an oscillating movement, and the ratchet-wheel is caused to rotate intermittently by a click operated by an eccentric on the crank-shaft, and hence the mirror has a compound movement.

5731. 5728. 5726. 5725. 5724.

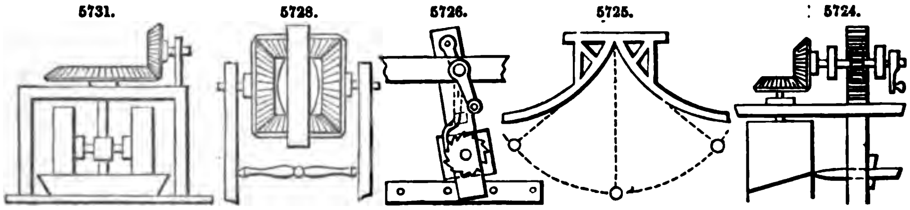


Fig. 5727. Modification of mangle-wheel motion. The large wheel is toothed on both faces, and an alternating circular motion is produced by the uniform revolution of the pinion, which passes from one side of the wheel to the other through an opening on the left of the figure.

Fig. 5728. White's dynamometer for determining the amount of power required to give rotary motion to any piece of mechanism. The two horizontal bevel-gears are arranged in a hoop-shaped frame, which revolves freely on the middle of the horizontal shaft, on which there are two vertical bevel-gears gearing to the horizontal ones, one fast and the other loose on the shaft. Suppose the hoop to be held stationary, motion given to either vertical bevel-gear will be imparted through the horizontal gears to the other vertical one; but if the hoop be permitted it will revolve with the vertical gear put in motion, and the amount of power required to hold it stationary will correspond with that transmitted from the first gear, and a band attached to its periphery will indicate that power by the weight required to keep it still.

Fig. 5729. Robert's contrivance for proving that friction of a wheel carriage does not increase with velocity, but only with load. Loaded wagon is supported on surface of large wheel, and connected with indicator constructed with spiral spring, to show force required to keep carriage

stationary when large wheel is put in motion. It was found that difference in velocity produced no variation in the indicator, but difference in weight immediately did so.

Fig. 5730. Rotary motion of shaft from treadle by means of an endless band running from a roller on the treadle to an eccentric on the shaft.

5737. 5736. 5735. 5730. 5729. 5727.

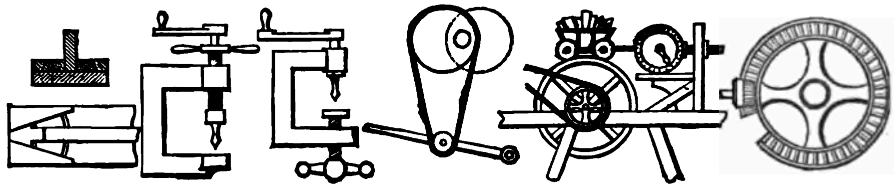


Fig. 5731. Pair of edge runners or chasers for crushing or grinding. The axles are connected with vertical shaft, and the wheels or chasers run in an annular pan or trough.

Fig. 5732. Tread-wheel horse-power turned by the weight of an animal attempting to walk up one side of its interior; has been used for driving the paddle-wheels of ferry-boats and other purposes by horses. The turn-spit dog used also to be employed in such a wheel in ancient times for turning meat while roasting on a spit.

Fig. 5733. The treadmill employed in jails in some countries for exercising criminals condemned to labour, and employed in grinding grain; turns by weight of persons stepping on tread-boards on periphery. This is supposed to be a Chinese invention, and it is still used in China for raising water for irrigation.

Fig. 5734. Saw for cutting trees by motion of pendulum, is represented as cutting a lying tree.

Figs. 5735, 5736. Portable cramp drills. In Fig. 5735 the feed-screw is opposite the drill, and in Fig. 5736 the drill-spindle passes through the centre of the feed-screw.

Fig. 5737. Bowery's joiner's clamp, plan and transverse section. Oblong bed has, at one end, two wedge-formed cheeks, adjacent sides of which lie at an angle to each other, and are dovetailed inward from upper edge to receive two wedges for clamping the piece or pieces of wood to be planed.

5744 5739. 5738. 5734. 5733. 5732.

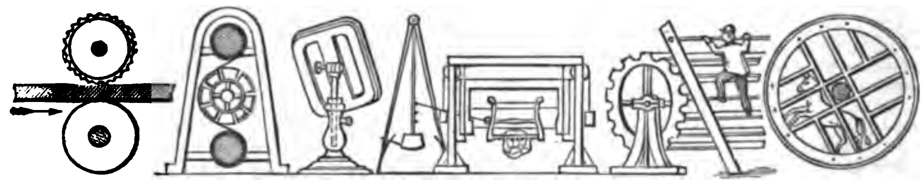


Fig. 5738. Adjustable stand for mirrors, by which a glass or other article can be raised or lowered, turned to the right or left, and varied in its inclination. The stem is fitted into a socket of pillar, and secured by a set screw, and the glass is hinged to the stem, and a set screw is applied to the hinge to tighten it. The same thing is used for photographic camera-stands.

Fig. 5739 represents the principal elements of machinery for dressing cloth and warps, consisting of two rollers, from one to the other of which the yarn or cloth is wound, and an interposed cylinder having its periphery either smooth-surfaced or armed with brushes, teasels, or other contrivances, according to the nature of the work to be done. These elements are used in machines for sizing warps, gig-mills for dressing woollen goods, and in most machines for finishing woven fabrics.

Fig. 5740. Helicograph, or instrument for describing helices. The small wheel, by revolving about the fixed central point, describes a volute or spiral by moving along the screw-threaded axle either way, and transmits the same to drawing paper on which transfer paper is laid with coloured side downward.

Fig. 5741. Contrivance employed in Russia for shutting doors. One pin is fitted to and turns in socket attached to door, and the other is similarly attached to frame. In opening the door, pins are brought together, and weight is raised. Weight closes door by depressing the joint of the toggle towards a straight line, and so widening the space between the pins.

Fig. 5742. Folding library ladder. It is shown open, partly open, and closed; the rounds are pivoted to the side-pieces, which are fitted together to form a round pole when closed, the rounds shutting up inside.

Fig. 5743. Self-adjusting step-ladder for wharfs at which there are rise and fall of tide. The steps are pivoted at one edge into wooden bars forming string-pieces, and their other edge is supported by rods suspended from bars forming hand-rails. The steps remain horizontal whatever position the ladder assumes.

Fig. 5744. Feed-motion of Woodworth's planing machine, a smooth supporting roller, and a toothed top roller.

Fig. 5745. Lifting jack operated by an eccentric, pawl, and ratchet. The upper pawl is a stop.

Fig. 5746. Device for converting oscillating into rotary motion. The semicircular piece A is attached to a lever which works on a fulcrum a, and it has attached to it the ends of two bands C and D, which run around two pulleys, loose on the shaft of the fly-wheel B. Band C is open, and band D crossed. The pulleys have attached to them pawls which engage with two ratchet-

wheels fast on the fly-wheel shaft. One pawl acts on its ratchet-wheel when the piece A turns one way, and the other when the said piece turns the other way, and thus a continuous rotary motion of the shaft is obtained.

Fig. 5747. Reciprocating into rotary motion. The weighted racks *a*, *a'*, are pivoted to the end of a piston-rod, and pins at the end of the said racks work in fixed guide-grooves *b*, *b*, in such manner that one rack operates upon the cog-wheel in ascending and the other in descending, and so continuous rotary motion is produced. The elbow-lever *c* and spring *d* are for carrying the pin of the right-hand rack over the upper angle in its guide-groove *b*.

5749. 5748. 5745. 5743. 5742. 5741.

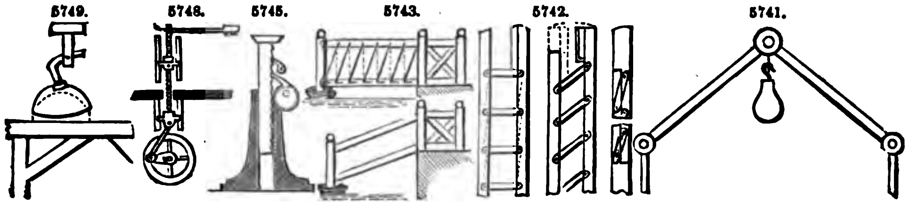


Fig. 5748. Gig-saw, the lower end connected with a crank which works it, and the upper end connected with a spring which keeps it strained without a gate.

Fig. 5749. Contrivance for polishing lenses and bodies of spherical form. The polishing material is in a cup connected by a ball-and-socket joint and bent piece of metal, with a rotating upright shaft set concentric to the body to be polished. The cup is set eccentric, and by that means is caused to have an independent rotary motion about its axis on the universal joint, as well as to revolve about the common axis of the shaft and the body to be polished. This prevents the parts of the surface of the cup from coming repeatedly in contact with the same parts of surface of the lens or other body.

5754. 5752. 5751. 5750. 5747. 5746.

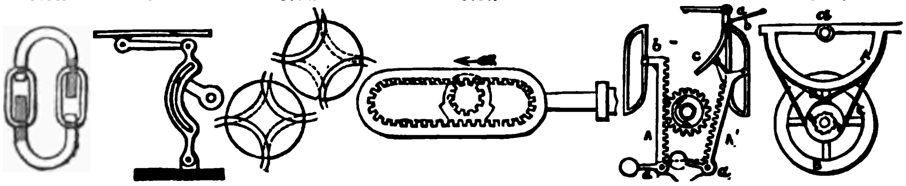


Fig. 5750. C. Parsons's device for converting reciprocating motion into rotary, an endless rack provided with grooves on its side gearing with a pinion having two concentric flanges of different diameters. A substitute for crank in oscillating cylinder engines.

Fig. 5751. Four-way cock, used many years ago on steam-engines to admit and exhaust steam from the cylinder. The two positions represented are produced by a quarter turn of the plug. Supposing the steam to enter at the top, in the upper figure the exhaust is from the right end of the cylinder, and in the lower figure the exhaust is from the left—the steam entering, of course, in the opposite port.

Fig. 5752. Continuous circular into intermittent rectilinear reciprocating. A motion used on several sewing machines for driving the shuttle. Same motion applied to three-revolution cylinder printing-presses.

Fig. 5753. Continuous circular motion into intermittent circular—the cam C being the driver.

Fig. 5754. A method of repairing chains, or tightening chains used as guys or braces. Link is made in two parts, one end of each is provided with swivel-nut, and other end with screw; the screw of each part fits into nut of other.

5759 5760. 5756. 5755. 5753.

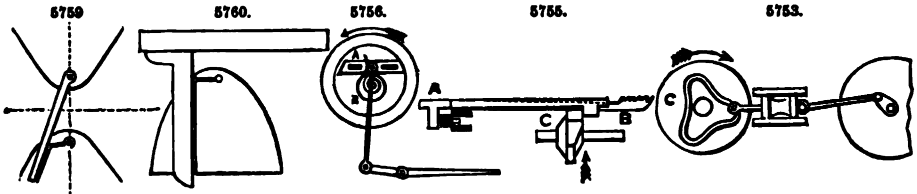


Fig. 5755. A. B. Wilson's four-motion feed, used in Wheeler and Wilson's, Sloat's, and other sewing machines. The bar A is forked, and has a second bar B, carrying the spur or feeder, pivoted in the said fork. The bar B is lifted by a radial projection on the cam C, at the same time the two bars are carried forward. A spring produces the return stroke, and the bar B drops of its own gravity.

Fig. 5756. E. P. Brownell's crank-motion to obviate dead-centres. The pressure on the treadle causes the slotted slide A to move forward with the wrist until the latter has passed the centre, when the spring B forces the slide against the stops until it is again required to move forward.

Fig. 5757. Cyclograph for describing circular arcs in drawings where the centre is inaccessible. This is composed of three straight rules. The chord and versed sine being laid down, draw straight sloping line, from ends of former to top of latter; and to these lines lay two of the rules crossing at the apex. Fasten these rules together, and another rule across them to serve as a brace, and insert a pin or point at each end of chord to guide the apparatus, which, on being moved against these points, will describe the arc by means of pencil in the angle of the crossing edges of the sloping rules.

Fig. 5758. Another cyclograph. The elastic arched bar is made half the depth at the ends that it is at the middle, and is formed so that its outer edge coincides with a true circular arc when bent to its greatest extent. Three points in the required arc being given, the bar is bent to them by means of the screw, each end being confined to the straight bar by means of a small roller.

Fig. 5759. Mechanical means of describing hyperbolas, their foci and vertices being given. Suppose the curves two opposite hyperbolas, the points in vertical dotted centre line their foci. One end of thread being looped on pin inserted at the other focus, and other end held to other end of rule, with just enough slack between to permit height to reach vortex when rule coincides with centre line. A pencil held in bight, and kept close to rule, while latter is moved from centre line, describes one-half of parabola; the rule is then reversed for the other half.

Fig. 5760. Mechanical means of describing parabolas, the base, altitude, focus, and directrix being given. Lay straight edge with near side coinciding with directrix, and square with stock against the same, so that the blade is parallel with the axis, and proceed with pencil in bight of thread, as in the preceding.

5766. 5762. 5761. 5758. 5757.

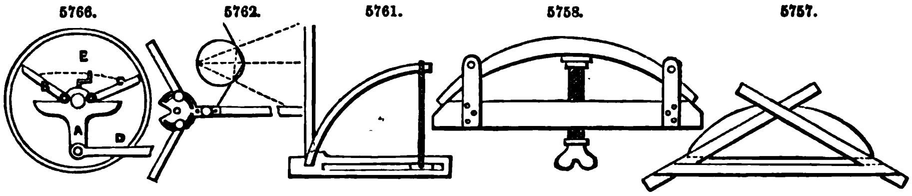


Fig. 5761. Instrument for describing pointed arches. Horizontal bar is slotted and fitted with a slide having pin for loop of cord. Arch bar of elastic wood is fixed in horizontal at right angles. Horizontal bar is placed with upper edge on springing line, and back of arch bar ranging with jamb of opening, and the latter bar is bent till the upper side meets apex of arch, fulcrum-piece at its base ensuring its retaining tangential relation to jamb; the pencil is secured to arched bar at its connection with cord.

Fig. 5762. Centrolinead for drawing lines toward an inaccessible or inconveniently distant point; chiefly used in perspective. Upper or drawing edge of blade and back of movable legs should intersect centre of joint. Geometrical diagram indicates mode of setting instruments, legs forming it may form unequal angles with blade. At either end of dotted line crossing central, a pin is inserted vertically for instrument to work against. Supposing it to be inconvenient to produce the convergent lines until they intersect, even temporarily, for the purpose of setting the instrument as shown, a corresponding convergence may be found between them by drawing a line parallel to and inward from each.

Fig. 5763. Proportional compasses used in copying drawings on a given larger or smaller scale. The pivot of compasses is secured in a slide which is adjustable in the longitudinal slots of legs, and capable of being secured by a set screw: the dimensions are taken between one pair of points and transferred with the other pair, and thus enlarged or diminished in proportion to the relative distances of the points from the pivot. A scale is provided on one or both legs to indicate the proportion.

5776. 5775. 5773 5772. 5771. 5769. 5763.

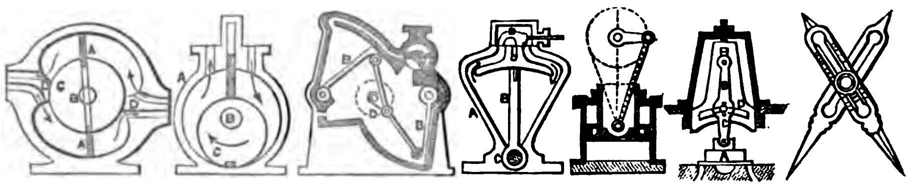


Fig. 5764. Bisecting gauge. Of two parallel cheeks on the cross-bar one is fixed and the other adjustable, and held by thumb-screw. In either cheek is entered one of two short bars of equal length, united by a pivot, having a sharp point for marking. This point is always in a central position between the cheeks, whatever their distance apart, so that any parallel-sided solid to which the cheeks are adjusted may be bisected from end to end by drawing the gauge along it. Solids not parallel-sided may be bisected in like manner, by leaving one cheek loose, but keeping it in contact with solid.

Fig. 5765. Self-recording level for surveyors, consists of a carriage, the shape of which is governed by an isosceles triangle, having horizontal base. The circumference of each wheel equals the base of the triangle. A pendulum, when the instrument is on level ground, bisects the base; and when on an inclination, gravitates to right or left from centre accordingly. A drum, rotated by gearing from one of the carriage wheels, carries sectionally ruled paper, upon which pencil on

pendulum traces profile corresponding with that of ground travelled over. The drum can be shifted vertically to accord with any given scale; and horizontally, to avoid removal of filled paper.

5770. 5768. 5767. 5765. 5764.

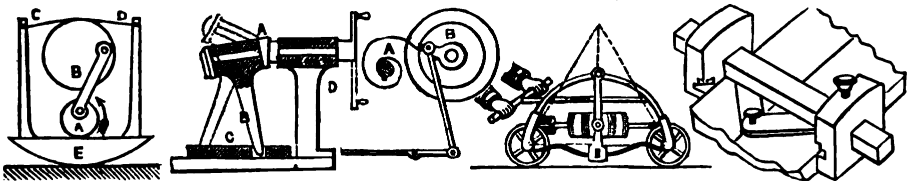


Fig. 5766. P. Dickson's device for converting an oscillating motion into intermittent circular, in either direction. Oscillating motion communicated to lever A, which is provided with two pawls B and C, hinged to its upper side, near shaft of wheel D. Small crank E on upper side of lever A is attached by cord to each of pawls, so that when pawl C is let into contact with interior of rim of wheel D, it moves in one direction, and pawl B is out of gear. Motion of wheel D may be reversed by lifting pawl C, which was in gear, and letting opposite one into gear by crank E.

Fig. 5767. A device for assisting the crank of a treadle motion over the dead-centres. The helical spring A has a tendency to move the crank B in direction at right angles to dead-centres.

Fig. 5768. Continuous circular motion into a rectilinear reciprocating. The shaft A, working in a fixed bearing D, is bent on one end, and fitted to turn in a socket at the upper end of a rod B, the lower end of which works in a socket in the slide C. Dotted lines show the position of the rod B and slide, when the shaft has made half a revolution from the position shown in bold lines.

Fig. 5769. Buchanan and Righter's slide-valve motion. Valve A is attached to lower end of rod B, and free to slide horizontally on valve-seat. Upper end of rod B is attached to a pin, which slides in vertical slots, and a roller C, attached to the said rod, slides in two suspended and vertically adjustable arcs D. This arrangement is intended to prevent the valve from being pressed with too great force against its seat by the pressure of steam, and to relieve it of friction.

Fig. 5770. Continuous circular motion converted into a rocking motion. Used in self-rocking cradles. Wheel A revolves and is connected to a wheel B, of greater radius, which receives an oscillating motion, and wheel B is provided with two flexible bands C, D, which connect each to a standard or post, attached to the rocker E of the cradle.

Fig. 5771. Trunk-engine used for marine purposes. The piston has attached to it a trunk, at the lower end of which the pitman is connected directly with the piston. The trunk works through a stuffing box in cylinder-head. The effective area of the upper side of the piston is greatly reduced by the trunk. To equalize the power on both sides of piston, high-pressure steam has been first used on the upper side, and afterward exhausted into and used expansively in the part of cylinder below.

Fig. 5772. Oscillating piston engine. The profile of the cylinder A is of the form of a sector. The piston B is attached to a rock-shaft C, and steam is admitted to the cylinder to operate on one and the other side of piston alternately, by means of a slide-valve D, substantially like that of an ordinary reciprocating engine. The rock-shaft is connected with a crank to produce rotary motion.

Fig. 5773. Root's double-quadrant engine. This is on the same principle as Fig. 5772; but two single-acting pistons B, B, are used, and both connected with one crank D. The steam is admitted to act on the outer sides of the two pistons alternately by means of one induction-valve *a*, and is exhausted through the space between the pistons. The piston and crank connections are such that the steam acts on each piston during about two-thirds of the revolution of the crank, and hence there are no dead-points.

Fig. 5774. Root's double-reciprocating or square piston engine. The cylinder A of this engine is of oblong square form, and contains two pistons B and C, the former working horizontally, and the latter working vertically within it. The piston C is connected with the wrist *a* of the crank on the main shaft *b*. The ports for the admission of steam are shown black. The two pistons produce the rotation of the crank without dead-points.

5789. 5786. 5779. 5778. 5777. 5774.

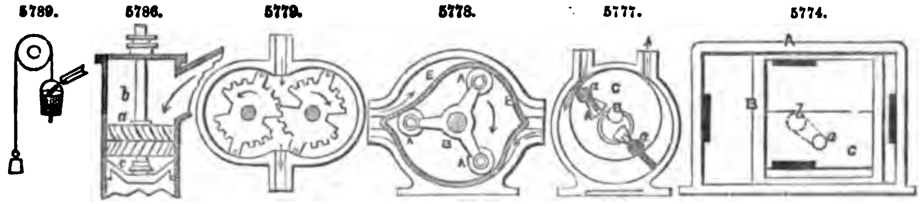


Fig. 5775. One of the many forms of rotary engine. A is the cylinder having the shaft B pass centrally through it. The piston C is simply an eccentric fast on the shaft, and working in contact with the cylinder at one point. The induction and eduction of steam take place as indicated by arrows, and the pressure of the steam on one side of the piston produces its rotation and that of the shaft. The sliding abutment D, between the induction and eduction ports, moves out of the way of the piston to let it pass.

Fig. 5776. Another form of rotary engine, in which there are two stationary abutments D, D, within the cylinder; and the two pistons A, A, in order to enable them to pass the abutments, are

made to slide radially in grooves in the hub C of the main shaft B. The steam acts on both pistons at once, to produce the rotation of the hub and shaft. The induction and eduction are indicated by arrows.

Fig. 5777. Another rotary engine, in which the shaft B works in fixed bearings, eccentric to the cylinder. The pistons A, A, are fitted to slide in and out from grooves in the hub C, which is concentric with the shaft, but they are always radial to the cylinder, being kept so by rings (shown dotted), fitting to hubs on the cylinder-heads. The pistons slide through rolling packings A, A, in the hub C.

Fig. 5778. The india-rubber rotary engine, in which the cylinder has a flexible lining E of india-rubber, and rollers A, A, are substituted for pistons, said rollers being attached to arms radiating from the main shaft B. The steam acting between the india-rubber and the surrounding rigid portion of the cylinder presses the india-rubber against the rollers, and causes them to revolve around the cylinder and turn the shaft.

Fig. 5779. Holly's double-elliptical rotary engine. The two elliptical pistons geared together are operated upon by the steam entering between them in such manner as to produce their rotary motion in opposite directions.

These rotary engines can all be converted into pumps.

Fig. 5780. Overshot water-wheel.

Fig. 5781. Undershot water-wheel.

Fig. 5782. Breast-wheel. This holds intermediate place between overshot and undershot wheels; has float-boards like the former, but the cavities between are converted into buckets by moving in a channel adapted to circumference and width, and into which water enters nearly at the level of axle.

Fig. 5783. Horizontal overshot water-wheel.

Fig. 5784. A plan view of the Fourneyron turbine water-wheel. In the centre are a number of fixed curved shutes or guides A, which direct the water against the buckets of the outer wheel B, which revolves, and the water discharges at the circumference.

Fig. 5785. Warren's central discharge turbine, plan view. The guides *a* are outside, and the wheel *b* revolves within them, discharging the water at the centre.

5785. 5784. 5783. 5782. 5781. 5780.

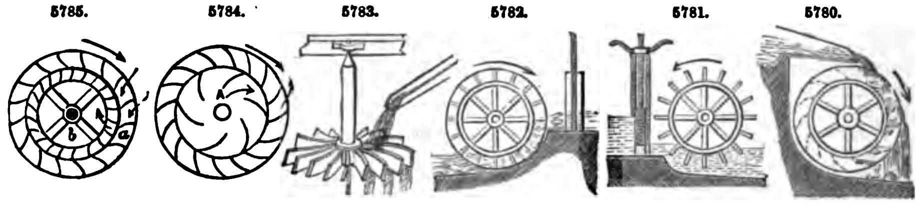


Fig. 5786. Jonval turbine. The shutes are arranged on the outside of a drum, radial to a common centre, and stationary within the trunk or casing *b*. The wheel *c* is made in nearly the same way; the buckets exceed in number those of the shutes, and are set at a slight tangent instead of radially, and the curve generally used is that of the cycloid or parabola.

Fig. 5787. Volute wheel, having radial vanes *a*, against which the water impinges and carries the wheel around. The scroll or volute casing *b* confines the water in such a manner that it acts against the vanes all around the wheel. By the addition of the inclined buckets *c*, *c*, at the bottom, the water is made to act with additional force as it escapes through the openings of said buckets.

Fig. 5788. Barker, or reaction mill. Rotary motion of central hollow shaft is obtained by the reaction of the water escaping at the ends of its arms, the rotation being in a direction the reverse of the escape.

5793 5792. 5791. 5790. 5788. 5787.

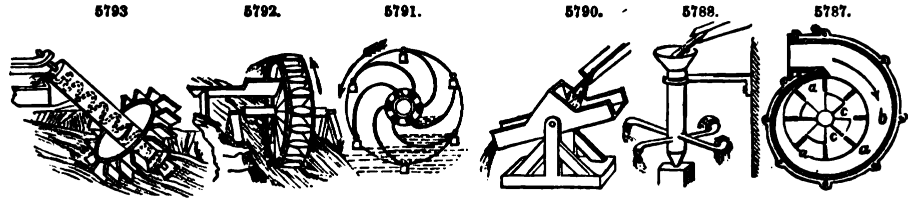


Fig. 5789. A method of obtaining a reciprocating motion from a continuous fall of water, by means of a valve in the bottom of the bucket which opens by striking the ground, and thereby emptying the bucket, which is caused to rise again by the action of a counterweight on the other side of the pulley over which it is suspended.

Fig. 5790 represents a trough divided transversely into equal parts, and supported on an axis by a frame beneath. The fall of water filling one side of the division, the trough is vibrated on its axis, and at the same time that it delivers the water the opposite side is brought under the stream and filled, which in like manner produces the vibration of the trough back again. This has been used as a water meter.

Fig. 5791. Persian wheel, used in Eastern countries for irrigation. It has a hollow shaft and curved floats, at the extremities of which are suspended buckets or tubs. The wheel is partly

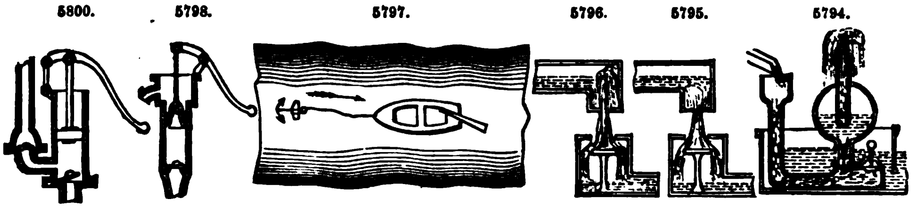
immersed in a stream acting on the convex surface of its floats; and as it is thus caused to revolve, a quantity of water will be elevated by each float at each revolution, and conducted to the hollow shaft at the same time that one of the buckets carries its fill of water to a higher level, where it is emptied by coming in contact with a stationary pin placed in a convenient position for tilting it.

Fig. 5792. Machine of ancient origin, still employed on the river Eisach, in the Tyrol, for raising water. A current keeping the wheel in motion, the pots on its periphery are successively immersed, filled, and emptied into a trough above the stream.

Fig. 5793. Application of Archimedes' screw to raising water, the supply stream being the motive power. The oblique shaft of the wheel has extending through it a spiral passage, the lower end of which is immersed in water, and the stream, acting upon the wheel at its lower end, produces its revolution, by which the water is conveyed upward continuously through the spiral passage and discharged at the top.

Fig. 5794. Montgolfier's hydraulic ram. Small fall of water made to throw a jet to a great height or furnish a supply at high level. The right-hand valve being kept open by a weight or spring, the current flowing through the pipe in the direction of the arrow escapes thereby till its pressure, overcoming the resistance of weight or spring, closes it. On the closing of this valve the momentum of the current overcomes the pressure on the other valve, opens it, and throws a quantity of water into the globular air-chamber by the expansive force of the air in which the upward stream from the nozzle is maintained. On equilibrium taking place, the right-hand valve opens and left-hand one shuts. Thus, by the alternate action of the valves, a quantity of water is raised into the air-chamber at every stroke, and the elasticity of the air gives uniformity to the efflux.

5800. 5798. 5797. 5796. 5795. 5794.



Figs. 5795, 5796. D'Ectol's oscillating column, for elevating a portion of a given fall of water above the level of the reservoir or head, by means of a machine, all the parts of which are absolutely fixed. It consists of an upper and smaller tube, which is constantly supplied with water, and a lower and larger tube, provided with a circular plate below concentric with the orifice which receives the stream from the tube above. Upon allowing the water to descend, as shown in Fig. 5795, it forms itself gradually into a cone on the circular plate, as shown in Fig. 5796, which cone protrudes into the smaller tube so as to check the flow of water downward; and the regular supply continuing from above, the column in the upper tube rises until the cone on the circular plate gives way. This action is renewed periodically, and is regulated by the supply of water.

Fig. 5797. This method of passing a boat from one shore of a river to the other is common on the Rhine and elsewhere, and is effected by the action of the stream on the rudder, which carries the boat across the stream in the arc of a circle, the centre of which is the anchor which holds the boat from floating down the stream.

Fig. 5798. Common lift-pump. In the up-stroke of piston or bucket the lower valve opens and the valve in piston shuts; air is exhausted out of suction-pipe, and water rushes up to fill the vacuum. In down-stroke lower valve is shut and valve in piston opens, and the water simply passes through the piston. The water above piston is lifted up, and runs over out of spout at each up-stroke. This pump cannot raise water over 30 ft. high.

Fig. 5799. Modern lifting pump. This pump operates in same manner as one in previous figure, except that piston-rod passes through stuffing box, and outlet is closed by a flap-valve opening upward. Water can be lifted to any height above this pump.

5814. 5806. 5805. 5803. 5802. 5801. 5799.

Fig. 5800. Ordinary force-pump, with two valves. The cylinder is above water, and is fitted with solid piston; one valve closes outlet-pipe, and other closes suction-pipe. When piston is rising suction-valve is open, and water rushes into cylinder, outlet-valve being closed. On descent of piston suction-valve closes, and water is forced up through outlet-valve to any distance or elevation.

Fig. 5801. Force-pump, same as above, with addition of air-chamber to the outlet, to produce a constant flow. The outlet from air-chamber is shown at two places, from either of which water may be taken. The air is compressed by the water during the downward stroke of the piston, and expands and presses out the water from the chamber during the up-stroke.

Fig. 5802. Double-acting pump. Cylinder closed at each end, and piston-rod passes through

stuffing box on one end, and the cylinder has four openings covered by valves, two for admitting water and like number for discharge. A is suction-pipe, and B discharge-pipe. When piston moves down, water rushes in at suction-valve 1, on upper end of cylinder, and that below piston is forced through valve 3 and discharge-pipe B; on the piston ascending again, water is forced through discharge-valve 4, on upper end of cylinder, and water enters lower suction-valve 2.

Fig. 5803. Double lantern-bellows pump. As one bellows is distended by lever, air is rarefied within it, and water passes up suction-pipe to fill space; at same time other bellows is compressed, and expels its contents through discharge-pipe; valves working the same as in the ordinary force-pump.

Fig. 5804. Diaphragm forcing pump. A flexible diaphragm is employed instead of bellows, and valves are arranged same as in preceding.

5823. 5810. 5809. 5808. 5807. 5804.

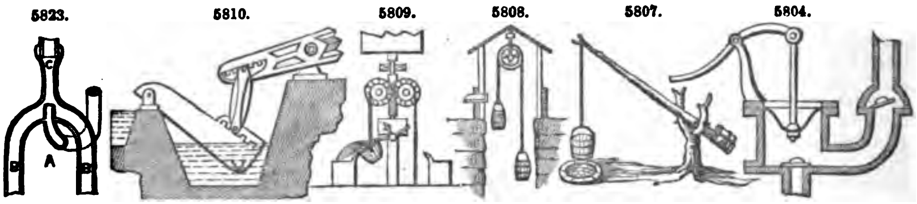


Fig. 5805. Old rotary pump. Lower aperture entrance for water, and upper for exit. Central part revolves with its valves, which fit accurately to inner surface of outer cylinder. The projection shown in lower side of cylinder is an abutment to close the valves when they reach that point.

Fig. 5806. Cary's rotary pump. Within the fixed cylinder there is placed a revolving drum B, attached to an axle A. Heart-shaped cam A, surrounding axle, is also fixed. Revolution of drum causes sliding pistons *c*, *c*, to move in and out, in obedience to form of cam. Water enters and is removed from the chamber through ports L and M; the directions are indicated by arrows. Cam is so placed that each piston is, in succession, forced back to its seat when opposite E, and at same time other piston is forced fully against inner side of chamber, thus driving before it water already there into exit-pipe H, and drawing after it, through suction-pipe F, the stream of supply.

Fig. 5807. Common mode of raising water from wells of inconsiderable depth. Counterbalance equals about one-half of weight to be raised, so that the bucket has to be pulled down when empty, and is assisted in elevating it when full by counterbalance.

Fig. 5808. The common pulley and buckets for raising water; the empty bucket is pulled down to raise the full one.

Fig. 5809. Reciprocating lift for wells. Top part represents horizontal wind-wheel on a shaft which carries spiral thread. Coupling of latter allows small vibration, that it may act on one worm-wheel at a time. Behind worm-wheels are pulleys, over which passes rope which carries bucket at each extremity. In centre is vibrating tappet, against which bucket strikes in its ascent, and which, by means of arm in step wherein spiral and shaft are supported, traverses spiral from one wheel to other, so that the bucket which has delivered water is lowered and other one raised.

Fig. 5810. Fairbairn's bailing scoop, for elevating water short distances. The scoop is connected by pitman to end of a lever or of a beam of single-acting engine. Distance of lift may be altered by placing end of rod in notches shown in figure.

Fig. 5811. Pendulums or swinging gutters for raising water by their pendulous motions. Terminations at bottom are scoops, and at top open pipes; intermediate angles are formed with boxes and flap-valve, each connected with two branches of pipe.

Fig. 5812. Chain pumps; lifting water by continuous circular motion. Wood or metal discs, carried by endless chain, are adapted to water-tight cylinder, and form with it a succession of buckets filled with water. Power is applied at upper wheel.

Fig. 5813. Self-acting weir and scouring sluice. Two leaves turn on pivots below centres; upper leaf much larger than lower, and turns in direction of stream, while lower turns against it. Top edge of lower leaf overlaps bottom edge of upper one, and is forced against it by pressure of water. In ordinary states of stream, counteracting pressures keep weir vertical and closed, as in the left-hand figure, and water flows through notch in upper leaf; but on water rising above ordinary level, pressure above from greater surface and leverage overcomes resistance below, upper leaf turns over, pushing back lower, reducing obstructions, and opening at bed a passage to deposit.

5819. 5818. 5815. 5813. 5812. 5811.

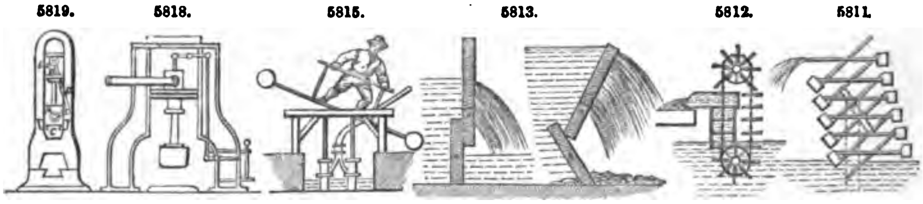


Fig. 5814. Hiero's fountain. Water being poured into upper vessel descends tube on right into lower; intermediate vessel being also filled and more water poured into upper, confined air in cavities over water in lower and intermediate vessels, and in communication tube on left, being compressed, drives by its elastic force a jet up central tube.

Fig. 5815. Balance pumps. Pair worked reciprocally by a person pressing alternately on opposite ends of lever or beam.

Fig. 5816. Flexible water-main, plan and section. Two pipes of 15 in. and 18 in. interior diameter, having some of their joints thus formed, conduct water across the Clyde to Glasgow Water-works. Pipes are secured to strong log frames, having hinges with horizontal pivots. Frames and pipes were put together on south side of the river, and, the north end of pipe being plugged, they were hauled across by machinery on north side, their flexible structure enabling them to follow the bed.

Fig. 5817. French invention for obtaining rotary motion from different temperatures in two bodies of water. Two cisterns contain water; that in left at natural temperature, and that in right higher. In right is a water-wheel geared with Archimedean screw in left. From spiral screw of the latter a pipe extends over and passes to the under side of wheel. Machine is started by turning screw in opposite direction to that for raising water, thus forcing down air, which ascends in tube, crosses and descends, and imparts motion to wheel; and its volume increasing with change of temperature, it is said, keeps the machine in motion. We are not informed how the difference of temperature is to be maintained.

5826. 5822. 5821. 5820. 5816. 5817.

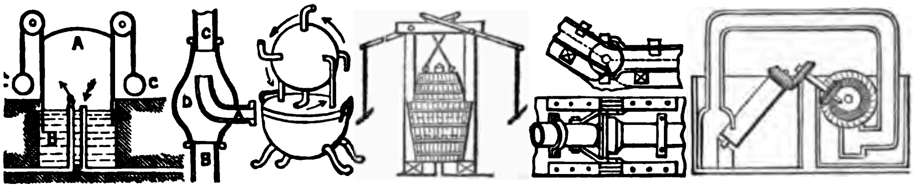


Fig. 5818. Steam-hammer. Cylinder fixed above and hammer attached to lower end of piston-rod. Steam being alternately admitted below piston and allowed to escape, raises and lets fall the hammer.

Fig. 5819. Hotchkiss's atmospheric hammer; derives the force of its blow from compressed air. Hammer-head C is attached to a piston fitted to a cylinder B, which is connected by a rod D with a crank A on the rotary driving shaft. As the cylinder ascends, air entering hole *e* is compressed below piston and lifts hammer. As cylinder descends, air entering hole *e* is compressed above, and is stored up to produce the blow by its instant expansion after the crank and connecting rod turn bottom centre.

Fig. 5820. Air-pump of simple construction. Smaller tube inverted in larger one. The latter contains water to upper dotted line, and the pipe from shaft or space to be exhausted passes through it to a few inches above water, terminating with valve opening upward. Upper tube has short pipe and upwardly-opening valve at top, and is suspended by ropes from levers. When upper tube descends, great part of air within is expelled through upper valve, so that, when afterward raised, rarefaction within causes gas or air to ascend through the lower valve. This pump was successfully used for drawing off carbonic acid from a large and deep shaft.

Fig. 5821. Aeolipile, or Hero's steam toy, described by Hero of Alexandria, 130 years B.C., and now regarded as the first steam-engine, the rotary form of which it may be considered to represent. From the lower vessel, or boiler, rise two pipes conducting steam to globular vessel above, and forming pivots on which the said vessel is caused to revolve in the direction of arrows, by the escape of steam through a number of bent arms. This works on the same principle as Barker's mill.

Fig. 5822. Brear's bilge ejector, for discharging bilge-water from vessels, or for raising and forcing water under various circumstances. D is a chamber having attached a suction-pipe B and discharge-pipe C, and having a steam-pipe entering at one side, with a nozzle directed toward the discharge-pipe. A jet of steam entering through A expels the air from D and C, produces a vacuum in B, and causes water to rise through B, and pass through D and C in a regular and constant stream. Compressed air may be used as a substitute for steam.

Fig. 5823. Another apparatus operating on the same principle as the foregoing. It is termed a Lansdell's steam siphon pump. A is the jet-pipe; B, B, are two suction-pipes, having a forked connection with the discharge-pipe C. The steam jet-pipe entering at the fork offers no obstacle to the upward passage of the water, which moves upward in an unbroken current.

Fig. 5824. Hoard and Wiggin's steam trap for shutting in steam, but providing for the escape of water from steam coils and radiators. It consists of a box, connected at A with the end of the coil or the waste-pipe, having an outlet at B and furnished with a hollow valve D, the bottom of which is composed of a flexible diaphragm. Valve is filled with liquid, and hermetically sealed, and its diaphragm rests upon a bridge over the outlet-pipe. The presence of steam in the outer box so heats the water in valve that the diaphragm expands and raises valve up to the seat *a a*. Water of condensation accumulating reduces the temperature of valve; and as the liquid in valve contracts, diaphragm allows valve to descend and let water off.

Fig. 5825. Ray's steam trap. Valve *a* closes and opens by longitudinal expansion and contraction of waste-pipe A, which terminates in the middle of an attached hollow sphere C. A portion of the pipe is firmly secured to a fixed support B. Valve consists of a plunger which works in a stuffing box in the sphere, opposite the end of the pipe, and it is pressed toward the end of the pipe by a loaded elbow lever D as far as permitted by a stop-screw *b* and stop *c*. When pipe is filled with water, its length is so reduced that valve remains open; but when filled with steam it is expanded so that valve closes it. Screw *b* serves to adjust the action of valve.

Fig. 5826. Gasometer. The open-bottomed vessel A is arranged in the tank B of water, and

partly counterbalanced by weights C, C. Gas enters the gasometer by one and leaves it by the other of the two pipes inserted through the bottom of the tank. As gas enters, vessel A rises, and *vice versâ*. The pressure is regulated by adding to or reducing the weights C, C.

5830. 5829. 5828. 5827. 5825. 5824.

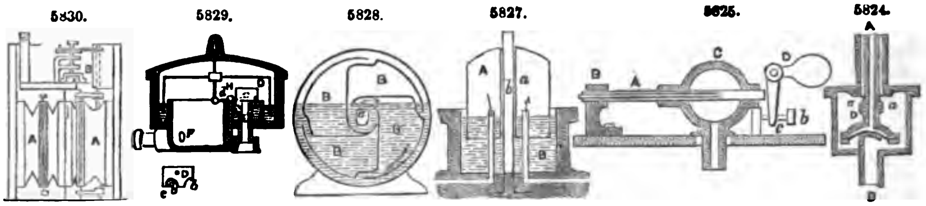


Fig. 5827 Another kind of gasometer. The vessel A has permanently secured within it a central tube *a* which slides in a fixed tube *b* in the centre of the tank.

Fig. 5828. Wet gas meter. The stationary case A is filled with water up to above the centre. The inner revolving drum is divided into four compartments B, B, with inlets around the central pipe *a* which introduces the gas through one of the hollow journals of the drum. This pipe is turned up to admit the gas above the water, as indicated by the arrow near the centre of the figure. As gas enters the compartments B, B, one after another, it turns the drum in the direction of the arrow shown near its periphery, displacing the water from them. As the chambers pass over they fill with water again. The cubic contents of the compartments being known, and the number of the revolutions of the drum being registered by dial-work, the quantity of gas passing through the meter is registered.

Fig. 5829. Powers's gas regulator for equalizing the supply of gas to all the burners of a building or apartment, notwithstanding variations in the pressure on the main, or variations produced by turning gas on or off, to or from any number of the burners. The regulator-valve D, of which a separate outside view is given, is arranged over inlet-pipe E, and connected by a lever *d*, with an inverted cup H, the lower edges of which, as well as those of valve, dip into channels containing quicksilver. There is no escape of gas around the cup H, but there are notches *b* in the valve to permit the gas to pass over the surface of the quicksilver. As the pressure of gas increases it acts upon the inner surface of cup H, which is larger than valve, and the cup is thereby raised, causing a depression of the valve into the quicksilver, and contracting the opening notches *b*, and diminishing the quantity of gas passing through. As the pressure diminishes, an opposite result is produced. The outlet to burners is at F.

Fig. 5830. Dry gas meter. Consists of two bellows-like chambers A, A, which are alternately filled with gas and discharged through a valve B, something like the slide-valve of a steam-engine, worked by the chambers A, A. The capacity of the chambers being known, and the number of times they are filled being registered by dial-work, the quantity of gas passing through the meter is indicated on the dials.

Fig. 5831. A spiral wound round a cylinder to convert the motion of the wind, or a stream of water, into rotary motion.

Fig. 5832. Common windmill, illustrating the production of circular motion by the direct action of the wind upon the oblique sails.

Fig. 5833. Plan of a vertical windmill. The sails are so pivoted as to present their edges in returning toward the wind, but to present their faces to the action of the wind, the direction of which is supposed to be as indicated by the arrow.

Fig. 5834. Common paddle-wheel for propelling vessels. The revolution of the wheel causes the buckets to press backward against the water, and so produce the forward movement of the vessel.

5839. 5836. 5835. 5834. 5833. 5832. 5831.

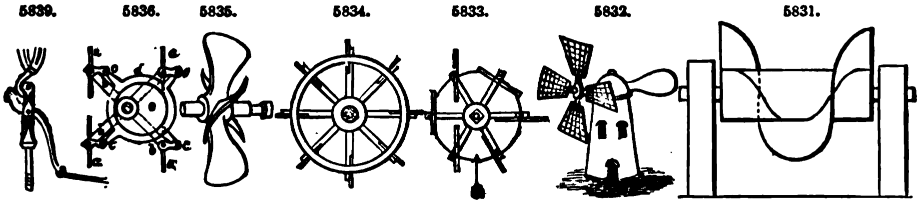


Fig. 5835. Screw-propeller. The blades are sections of a screw-thread, and their revolution in the water has the same effect as the working of a screw in a nut, producing motion in the direction of the axis, and so propelling the vessel.

Fig. 5836. Vertical bucket paddle-wheel. The buckets *a*, *a*, are pivoted into the arms *b*, *b*, at equal distances from the shaft. To the pivots are attached cranks *c*, *c*, which are pivoted at their ends to the arms of a ring *d*, which is fitted loosely to a stationary eccentric *e*. The revolution of the arms and buckets with the shaft causes the ring *d* also to rotate upon the eccentric, and the action of this ring on the cranks keeps the buckets always upright, so that they enter the water and leave it edgewise without resistance or lift, and while in the water are in the most effective position for propulsion.

Fig. 5837 Ordinary steering apparatus. Plan view. On the shaft of the hand-wheel there is a barrel, on which is wound a rope, which passes round the guide-pulleys and has its opposite ends attached to the tiller, or lever, on top of the rudder; by turning the wheel, one

end of the rope is wound on and the other let off, and the tiller is moved in one or the other direction, according to the direction in which the wheel is turned.

Fig. 5838. Capstan. The cable or rope wound on the barrel of the capstan is hauled in by turning the capstan on its axis by means of handspikes, or bars inserted into holes in the head. The capstan is prevented from turning back by a pawl attached to its lower part and working in a circular ratchet on the base.

Fig. 5839. Brown and Level's boat-detaching hook. The upright standard is secured to the boat, and the tongue, hinged to its upper end, enters an eye in the level, which works on a fulcrum at the middle of the standard. A similar apparatus is applied at each end of the boat. The hooks of the tackles hook into the tongues, which are secure until it is desired to detach the boat, when a rope attached to the lower end of each lever is pulled in such a direction as to slip the eye at the upper end of the lever from off the tongue, which, being then liberated, slips out of the hook of the tackle and detaches the boat.

Fig. 5840. Lewis, for lifting stone in building. It is composed of a central taper pin or wedge, with two wedge-like packing pieces arranged one on each side of it. The three pieces are inserted together in a hole drilled into the stone, and when the central wedge is hoisted upon it wedges the packing pieces out so tightly against the sides of the hole as to enable the stone to be lifted.

5847. 5844. 5843. 5842. 5841. 5840. 5838. 5837.

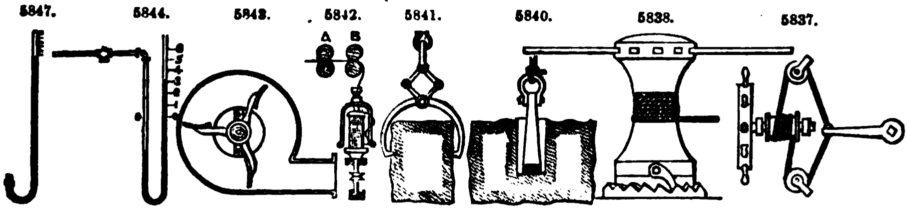


Fig. 5841. Tongs for lifting stones. The pull on the shackle which connects the two links causes the latter so to act on the upper arms of the tongs as to make their points press themselves against or into the stone. The greater the weight the harder the tongs bite.

Fig. 5842. Drawing and twisting in spinning cotton, wool, &c. The front drawing-rolls B rotate faster than the back ones A, and so produce a draught, and draw out the fibres of the sliver or roving passing between them. Roving passes from the front drawing-rolls to throstle, which, by its rotation around the bobbin, twists and winds the yarn on the bobbin.

Fig. 5843. Fan-blower. The casing has circular openings in its sides, through which, by the revolution of the shaft and attached fan-blades, air is drawn in at the centre of the casing, to be forced out under pressure through the spout.

Fig. 5844. Siphon pressure gauge. Lower part of bent tube contains mercury. The leg of the tube, against which the scale is marked, is open at top, the other leg connected with the steam-boiler or other apparatus on which the pressure is to be indicated. The pressure on the mercury in the one leg causes it to be depressed in that and raised in the other, until there is an equilibrium established between the weight of mercury and pressure of steam in one leg, and the weight of mercury and pressure of atmosphere in the other. This is the most accurate gauge known; but as high pressure requires so long a tube, it has given place to those which are practically accurate enough, and of more convenient form.

Fig. 5845. Aneroid gauge, known as the Bourdon gauge, from the name of its inventor, a Frenchman. B is a bent tube closed at its ends, secured at C, the middle of its length, and having its ends free. Pressure of steam or other fluid admitted to tube tends to straighten it more or less, according to its intensity. The ends of tube are connected with a toothed sector-piece, gearing with a pinion on the spindle of a pointer, which indicates the pressure on a dial.

Fig. 5846. Pressure gauge now seldom used. Sometimes known as the Madgeburg gauge, from the name of the place where first manufactured. Face view and section. The fluid whose pressure is to be measured acts upon a circular metal disc A, generally corrugated, and the deflection of the disc under the pressure gives motion to a toothed sector *e*, which gears with a pinion on the spindle of the pointer.

Fig. 5847. Mercurial barometer. Longer leg of bent tube, against which is marked the scale of inches, is closed at top, and shorter one is open to the atmosphere, or merely covered with some porous material. Column of mercury in longer leg, from which the air has been extracted, is held up by the pressure of air on the surface of that in the shorter leg, and rises or falls as the pressure of the atmosphere varies. The old-fashioned weather-glass is composed of a similar tube attached to the back of a dial, and a float inserted into the shorter leg of the tube, and geared by a rack and pinion, or cord and pulley, with the spindle of the pointer.

Fig. 5848. An epicyclic train. Any train of gearing the axes of the wheels of which revolve around a common centre is properly known by this name. The wheel at one end of such a train, if not those at both ends, is always concentric with the revolving frame. C is the frame or train-bearing arm. The centre wheel A, concentric with this frame, gears with a pinion F to the same axle, with which is secured a wheel E that gears with a wheel B. If the first wheel A be fixed, and a motion be given to the frame C, the train will revolve around the fixed wheel, and the relative motion of the frame to the fixed wheel will communicate through the train a rotary motion to B on its axis. Or the first wheel as well as the frame may be made to revolve with different velocities, with the same result except as to the velocity of rotation of B upon its axis.

In the epicyclic train as thus described, only the wheel at one extremity is concentric with the revolving frame; but if the wheel E, instead of gearing with B, be made to gear with the wheel D,

which, like the wheel A, is concentric with the frame, we have an epicyclic train, of which the wheels at both extremities are concentric with the frame. In this train we may either communicate the driving motion to the arm and one extreme wheel, in order to produce an aggregate rotation of the other extreme wheel, or motion may be given to the two extreme wheels A and D of the train, and the aggregate motion will thus be communicated to the arm.

5850. 5849.

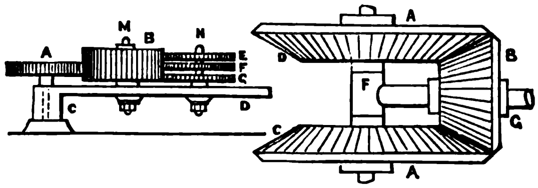


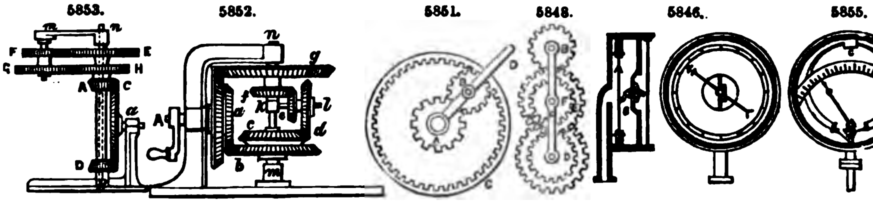
Fig. 5849. A very simple form of the epicyclic train, in which F, G, is the arm, secured to the central shaft A. upon which are loosely fitted the bevel-wheels C, D. The arm is formed into an axle for the bevel-wheel B, which is fitted to turn freely upon it. Motion may be given to the two wheels C, D, in order to produce aggregate motion of the arm, or else to the arm and one of said wheels in order to produce aggregate motion of the other wheel.

Fig. 5850. Ferguson's mechanical paradox, designed to show a curious property of the epicyclic train. The wheel A is fixed upon a stationary stud, about which the arm C, D, revolves. In this arm are two pins M, N, upon one of which is fitted loosely a thick wheel B gearing with A, and upon the other are three loose wheels E, F, G, all gearing with B. When the arm C, D, is turned round on the stud, motion is given to the three wheels E, F, G, on their common axis, namely, the pin N; the three forming with the intermediate wheel B and the wheel A three distinct epicyclic trains. Suppose A to have twenty teeth, F twenty, E twenty-one, and G nineteen; as the arm E, C, D, is turned round F will appear not to turn on its axis, as any point in its circumference will always point in one direction, while E will appear to turn slowly in one, and G in the other direction, which—an apparent paradox—gave rise to the name of the apparatus.

Fig. 5851. Another simple form of the epicyclic train, in which the arm D carries a pinion B, which gears both with a spur-wheel A and an annular wheel C, both concentric with the axis of the arm. Either of the wheels A, C, may be stationary, and the revolution of the arm and pinion will give motion to the other wheel.

Fig. 5852. Another epicyclic train in which neither the first nor last wheel is fixed. *m*, *n*, is a shaft to which is firmly secured the train-bearing arm *k*, *l*, which carries the two wheels *d*, *e*, secured together but rotating upon the arm itself. The wheels *b* and *c* are united, and turn together freely upon the shaft *m*, *n*; the wheels *f* and *g* are also secured together, but turn together freely on the shaft *m*, *n*. The wheels *c*, *d*, *e*, and *f*, constitute an epicyclic train, of which *c* is the first and *f* the last wheel. A shaft A is employed as a driver, and has firmly secured to it two wheels *a* and *h*, the first of which gears with the wheel *b*, and thus communicates motion to the first wheel *c* of the epicyclic train, and the wheel *h* drives the wheel *g*, which thus gives motion to the last wheel *f*. Motion communicated this way to the two ends of the train produces an aggregate motion of the arm *k*, *l*, and shaft *m*, *n*.

5853. 5852. 5851. 5848. 5846. 5855.



This train may be modified; for instance, suppose the wheels *g* and *f* to be disunited, *g* to be fixed to the shaft *m*, *n*, and *f* only running loose upon it. The driving shaft A will, as before, communicate motion to the first wheel *c* of the epicyclic train by means of the wheels *a* and *b*, and will also by *h* cause the wheel *g*, the shaft *m*, *n*, and the train-bearing arm *k*, *l*, to revolve, and the aggregate rotation will be given to the loose wheel *f*.

Fig. 5853. Another form of epicyclic train, designed for producing a very slow motion. *m* is a fixed shaft, upon which is loosely fitted a long sleeve, to the lower end of which is fixed a wheel D, and to the upper end a wheel E. Upon this long sleeve there is fitted a shorter one which carries at its extremities the wheels A and H. A wheel C gears with both D and A, and a train-bearing arm *m*, *n*, which revolves freely upon the shaft *m*, *p* carries upon a stud at *n* the united wheels F and G If A have ten teeth, C one hundred, D ten, E sixty-one, F forty-nine, G forty-one, and H fifty-one, there will be 25,000 revolutions of the train-bearing arm *m*, *n*, for one of the wheel C.

MECHANICAL POWERS. Fr., *Machines simples, Puissances méchaniques*, Ger., *Mechanische Potenzen*; Span., *Fuerzas mécanicas.*

The Mechanical Powers are certain standard machines which enable us to apply, economically, large forces to produce small effects, and small forces to produce in time great effects, and which are further capable of transferring forces from their natural point of action, to another point of application. The mechanical powers are the lever, the wheel and axle, the pulley, the inclined plane, the wedge, the screw, and the toggle. To these sometimes are added the toothed wheel. None of these machines create new power, though several of them store up the successive additions of power which successive impulses give, until the sum total comes to be equal to the demand. All of the mechanical powers can be reduced to the two simplest, the lever and the inclined plane; and these derive their chief efficacy from the equivalence which they produce between parts of the

forces which prevent our results, and resistances that we can call into action in almost unlimited quantity. Thus the lever transfers the excess of the one weight over the other or the sum of the weights, to be borne by the fulcrum; and the inclined plane throws part of the gravitating forces upon the board which bears the weight. We shall merely enumerate the formulæ for what is called the mechanical advantage in each: that is, the value of $\frac{W}{P}$, where W is the weight, or more properly resistance, and P the power applied to overcome it. In the lever, $\frac{\text{the arm of the power}}{\text{the arm of the weight}}$, the arm being distance from fulcrum. In the wheel and axle, $\frac{\text{the radius of the wheel}}{\text{the radius of the axle}}$. In the pulley, this varies with the peculiar system of pulleys. In the inclined plane, $\frac{\text{the length of the plane}}{\text{the height of the plane}}$. In the wedge, $\frac{\text{the side of the wedge}}{\text{half the back of the wedge}}$. In the screw, $\frac{\text{the circumference described by the power}}{\text{the distance between two contiguous threads}}$. In the toothed wheel,

$$\frac{\text{the number of teeth in the wheel of W}}{\text{the number of teeth in the wheel of P}}.$$

For the toggle, see p. 618.

See MECHANICAL MOVEMENTS.

MERCURY. FR., *Argent vif, Mercure;* GER., *Quicksilver;* ITAL., *Argento vivo;* SPAN., *Mercurio.*

Mercury is remarkable as being the only metal that is fluid at ordinary temperatures; its atomic weight is 200; molecular weight, 200. It is of a silvery white colour, and possesses a striking metallic lustre. Native mercury occurs in cavities of the ores, but only in very small quantities; the chief source from which it is obtained is the sulphide of mercury, known as cinnabar, the principal mines of which are at Almaden, in Spain, and at Iddria, in Illyria. The metallurgical processes differ slightly with the locality as regards the arrangement of the apparatus employed, but chemically the same process is everywhere adopted, namely, that of roasting the ore. The heat, in this case, causes the sulphur to pass into the state of a sulphurous anhydride, and the mercury is liberated.

$$\underset{\text{Sulphide of mercury.}}{HgS} + \underset{\text{Oxygen.}}{\left.\begin{matrix}\Theta\\ \Theta\end{matrix}\right\}} = \underset{\text{Sulphurous anhydride.}}{S\Theta_2} + \underset{\text{Mercury.}}{Hg}$$

Mercury may also be obtained from its sulphide by heating the latter with iron.

$$\underset{\text{Sulphide of mercury.}}{HgS} + \underset{\text{Iron.}}{Fe} = \underset{\text{Sulphide of iron.}}{FeS} + \underset{\text{Mercury.}}{Hg}$$

The mercury obtained by one of these methods is filtered through chamois skins and enclosed in iron bottles. If it be required to obtain the metal pure, it must be acted upon by a quantity of nitric acid insufficient to dissolve it, and left for twenty-four hours. At first there is formed nitrate of mercury, and the foreign metals afterwards substitute themselves for the mercury of this nitrate. At the expiration of twenty-four hours, all these metals have entered into a state of solution, and the unattached portion of mercury remains in a state of absolute purity.

At a temperature of $-39°$ mercury freezes, when it contracts considerably, and becomes malleable; at 662° it boils, and forms a colourless vapour, the specific gravity of which is 6·976. In its liquid state its specific gravity is 14·4, and in a solid state 13·59. Pure mercury does not adhere to the smooth surfaces of glass or porcelain vessels, but when allied with lead or other metal it, on the contrary, adheres, and assumes the form of elongated or *tailed* drops. When exposed to the air mercury becomes oxidized, but slowly; this oxidation is greatly facilitated by a high temperature. Ozonised oxygen also readily causes oxidation at a low temperature. Hydrochloric acid has no effect upon it; but nitric acid dissolves it rapidly. When cold, and with an excess of metal, minimum nitrate of mercury is formed, and when heated with an excess of acid, maximum nitrate is produced. Boiling sulphuric acid dissolves mercury with a liberation of sulphurous anhydride; the sulphate resulting from the operation is either maximum or minimum, according as the metal or the acid predominates.

When exposed to the influence of the air and of acids, the alkaline chlorides cause mercury to pass into the state of a chloride. This reaction explains the absorption of the metal by the skin. Chlorine, bromine, and iodine combine directly with mercury, and the same may be said of sulphur. The absorbable mercurial compounds act as poison on the animal system, and those whose occupations expose them to the influence of these compounds are often attacked by a malady known as mercurial palsy.

Mercury, like copper, is diatomic, and its atoms, also like those of copper, possess the property of combining together while losing a portion only of their capacity of saturation. Hence it follows that not only the atom Hg, but the group Hg_2 acts as a diatomic radical, and is capable of entering into combination with the various radicals. The compounds in which the atom Hg enters are called maximum, or mercuric compounds, and those in which the group Hg_2 enters are known as minimum, or mercurous compounds. The principal maximum compounds are the following;—The bichloride of mercury, $HgCl_2$; the bromide, $HgBr_2$; the biiodide, HgI_2; the bifluoride, $HgFl_2$; the protoxide, $Hg\Theta$; and the protosulphide, HgS; to which must be added the maximum salts resulting from the substitution of the diatomic atom Hg for the basic hydrogen of the acids. The following are the principal minimum compounds;—The protochloride of mercury, Hg_2Cl_2, the protobromide, Hg_2Br_2; the protoiodide, Hg_2I_2; the suboxide, $Hg_2\Theta$; the subsulphide, Hg_2S; and the minimum salts resulting from the substitution of the diatomic radical Hg_2 for the typical hydrogen of the acids.

Mercuric Chloride, $Hg\begin{cases}Cl\\Cl\end{cases}$.—The bichloride of mercury has received the name of corrosive sublimate; it may be obtained by acting upon mercury with chlorine, or by distilling a compound of marine salt and maximum sulphate of mercury.

$$1.\quad \underset{\text{Mercury.}}{Hg} + \underset{\text{Chlorine.}}{\left.\begin{matrix}Cl\\Cl\end{matrix}\right\}} = \underset{\text{Mercuric chloride.}}{Hg\begin{cases}Cl\\Cl\end{cases}}$$

$$2.\quad \underset{\text{Mercuric sulphate.}}{\left.\begin{matrix}S\Theta\\Hg\end{matrix}\right\}\Theta_2} + \underset{\text{Chloride of sodium.}}{2\left(\left.\begin{matrix}Na\\Cl\end{matrix}\right\}\right)} = \underset{\text{Sulphate of sodium.}}{\left.\begin{matrix}S\Theta_2\\Na_2\end{matrix}\right\}\Theta_2} + \underset{\text{Corrosive sublimate.}}{Hg\begin{cases}Cl\\Cl\end{cases}}$$

As the mercuric sulphate nearly always contains a small quantity of mercurous sulphate which would give protochloride Hg_2Cl_2, by reacting upon the iodic chloride, when the second method is employed, it is usual to add a little bioxide of manganese to the compound. On coming in contact with the chloride of sodium, and the excess of acid that the mercuric sulphate always contains, this bioxide causes a slight evolution of chlorine, which converts the small quantity of protochloride into bichloride.

$$\underset{\text{Protochloride of mercury.}}{Hg_2Cl_2} + \underset{\text{Chlorine.}}{\left.\begin{matrix}Cl\\Cl\end{matrix}\right\}} = \underset{\text{Bichloride of mercury.}}{2\,HgCl_2}$$

Bichloride of mercury dissolves more readily in boiling than in cold water. Alcohol dissolves it better than water, and ether better than alcohol; its alcoholic solution leaves it, by evaporation, crystallized in right prisms with a rhomboidal base; by sublimation it crystallizes in rectangular octahedrons. Its specific gravity is 6·5; as a vapour its gravity is 9·42. It fuses at about 509°, and boils at 570°.

By acting upon a solution of sublimate with a reducing substance, such as the protochloride of tin, we obtain a white precipitate of protochloride of mercury; and if the compound be boiled the protochloride is reduced to the state of metallic mercury. If a solution of sublimate is poured into ammonia, a white precipitate is thrown down, which has received the name of chloro-amide of mercury, and which is represented by the formula $\left.\begin{matrix}Hg\\Hg\\H_4\end{matrix}\right\}N_2, Cl_2$. If, on the contrary, ammonia is poured into the solution of sublimate, a white substance is thrown down represented by the formula $(HgCl_2)^2, HgH_4N_2$; this latter substance may be regarded as a combination of bichloride and amide of mercury. Albumen gives with the sublimate an insoluble precipitate, the composition of which is imperfectly known, and which seems to vary with age. The sublimate has a strong tendency to form double chlorides with the alkaline chlorides. The formula of these salts is $\left.\begin{matrix}Hg\\Cl_2\end{matrix}\right\}, 2\left(\left.\begin{matrix}Na\\Cl\end{matrix}\right\}\right)$.

The sublimate is a violent poison, and the best antidote is a glass or two of albuminous water, followed by an emetic. The albumen, by rendering the sublimate insoluble, prevents it from being absorbed before the emetic has had time to take effect. The action of corrosive sublimate upon albumen renders it useful in preserving animal matters. It is one of the compounds which serve as a base to the mercurial pharmaceutical preparations.

Mercuric Bromide, $Hg\begin{cases}Br\\Br\end{cases}$.—This substance is prepared by the same methods as the chloride, and it possesses similar properties.

Biiodide of Mercury, $Hg\begin{cases}I\\I\end{cases}$.—The biiodide may be obtained either directly or by double decomposition. To obtain it directly, 200 parts of mercury are pounded in a mortar with 254 parts of iodine to render the operation easier, a little alcohol is added, and the pounding is continued until the mass assumes a beautiful red colour, and no globule of metallic mercury is visible under the magnifying glass. To obtain it by double decomposition, a watery solution of 318 parts of potassic iodide is added to a watery solution of 271 parts of corrosive sublimate, when a beautiful orange red precipitate of biiodide of mercury is thrown down.

$$\underset{\text{Bichloride of mercury.}}{Hg\left.\begin{matrix}Cl\\Cl\end{matrix}\right\}} + \underset{\text{Iodide of potassium.}}{2\left(\left.\begin{matrix}K\\I\end{matrix}\right\}\right)} = \underset{\text{Chloride of potassium.}}{2\left(\left.\begin{matrix}K\\Cl\end{matrix}\right\}\right)} + \underset{\text{Mercuric iodide.}}{Hg\begin{cases}I\\I\end{cases}}$$

If an excess of either reagent were employed in the place of the atomic proportions given above, the precipitate would be redissolved.

When biiodide of mercury is dissolved in a boiling solution of iodide of potassium, a portion of this iodide is deposited in crystals by the cooling of the liquor; the crystals so obtained are red. Biiodide of mercury is sufficiently volatile to be sublimed; in this case it is deposited in yellow crystals, which become red when pulverized, and during this latter transformation, heat is evolved. The yellow crystals of biiodide of mercury belong to the fourth crystalline system, whilst the red crystals belong to the second; this salt is, therefore, a dimorphous substance. The biiodide combines with the alkaline iodides; the double iodides which it forms are represented by the formula $\left.\begin{matrix}Hg\\I_2\end{matrix}\right\}, 2\left(\left.\begin{matrix}M\\Cl\end{matrix}\right\}\right)$.

Protosulphide of Mercury, HgS.—This substance may be prepared by heating sulphur and mercury together, or by precipitating a maximum salt of mercury by sulphuretted hydrogen.

$$\underset{\text{Bichloride of mercury.}}{Hg\begin{cases}Cl\\Cl\end{cases}} + \underset{\text{Sulphuretted hydrogen.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}S} = \underset{\text{Hydrochloric acid.}}{2\left(\left.\begin{matrix}H\\Cl\end{matrix}\right\}\right)} + \underset{\text{Sulphide of mercury}}{Hg\,S}$$

In the latter case, the sulphide of mercury constitutes a black mass. This mass, when dried and heated in balloons with an open neck, becomes volatilized, and is sublimed upon the cold portions of the balloons in crystals of a violet-red colour. These crystals are identical with those found in nature, and known by the name of cinnabar. The sulphide of mercury is therefore dimorphous like the iodide. It becomes volatilized at a high temperature without being decomposed if protected from the air; but in a current of air, it is converted into mercury and sulphurous anhydride.

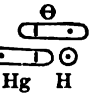
$$\underset{\text{Sulphide of mercury.}}{Hg\,S} + \underset{\text{Oxygen.}}{\left.\begin{matrix}\Theta\\\Theta\end{matrix}\right\}} = \underset{\text{Sulphurous anhydride.}}{S\,\Theta_2} + \underset{\text{Mercury.}}{Hg}$$

The specific gravity of natural cinnabar is 8·1; but that of the artificial substance may be as low as 7·65. There exists a variety of mercuric sulphide that is of a much purer red than cinnabar. This variety, known as vermilion, is prepared by triturating for several hours a compound consisting of 300 parts of mercury, 114 of sulphur, 400 of water, and 75 of potassa. The mass thus formed is black, but after it has been exposed for some time to a temperature of 122°, it assumes a beautiful red colour. The vermilion hue, which makes it valuable as a pigment, is attributed to the influence of the alkaline sulphide formed in the reaction.

Protoxide of Mercury.—There are two varieties of protoxide, as there are two of sulphide and iodide; one of these varieties is yellow, the other red. Protoxide of mercury, in its yellow variety, is obtained by precipitating a salt of mercury by a soluble base.

$$\underset{\text{Chloride of mercury.}}{Hg\begin{cases}Cl\\Cl\end{cases}} + \underset{\text{Potassa.}}{2\left(\left.\begin{matrix}K\\H\end{matrix}\right\}\Theta\right)} = \underset{\text{Chloride of potassium.}}{2\left(\left.\begin{matrix}K\\Cl\end{matrix}\right\}\right)} + \underset{\text{Protoxide of potassium.}}{Hg\,\Theta} + \underset{\text{Water.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}\Theta}$$

The precipitate thus obtained is anhydrous; it has merely to be collected upon a filter and washed and dried. The red oxide is prepared either by heating mercury while exposed to the air, or by slightly calcining nitrate of mercury. The oxide obtained from the maximum nitrate is redder than that obtained from the minimum nitrate. The process of heating mercury in contact with the air is no longer resorted to. We owe to it the name of *precipitate per se*, which the bioxide still bears in pharmacy. Oxide of mercury is decomposed at 752°, so that between the temperature at which the metal becomes oxidized and that at which it is reduced, there is a difference of hardly more than 122°. One part of this oxide appears to dissolve in from 20 to 30 parts of water; the solution does not act upon litmus, but if marine salt be added, chloride of mercury and hydrate of sodium are formed, and the alkaline reaction manifests itself with intensity. A blue light appears to reduce the bioxide of mercury, but a white light does not affect it. The yellow oxide, if allowed to remain in a flask with ammonia, combines with the elements of this substance without changing colour. The product thus formed is a powerful base which combines with the acids without undergoing decomposition, and form well-defined salts. These salts have been named ammonio-mercuric salts. The base corresponds to the formula $(Hg\,\Theta)^3\,N_2\,Hg\,H_4 + 3\,H_2\,\Theta$. Supposing the water which it contains to be water of crystallization, we may represent the ammonio-mercuric oxide by the following formula;—$\left.\begin{matrix}Hg\\(Hg\,\Theta\,H)\\(Hg\,\Theta\,H)\\(Hg\,\Theta\,H)\\H\end{matrix}\right\}N_2 + 3\,aq.$ This would be a double-condensed ammonia in which diatomic Hg held the place of H_2, and in which three times the monatomic residue $(Hg\,\Theta\,H)$ was substituted for 3 H.


$= (Hg\,\Theta\,H)$.

Nitrate of Mercury (Mercuric Nitrate), $Hg\begin{cases}\Theta\,N\,\Theta_2\\\Theta\,N\,\Theta_2\end{cases}$.—When mercury is dissolved in an excess of boiling nitric acid and the concentrated solution left to evaporate spontaneously in vacuo, crystals of basic nitrate of mercury are formed, and the liquor holds in solution uncrystallizable neutral nitrate of mercury; water throws down another basic nitrate from this solution.

Sulphate of Mercury, $\left.\begin{matrix}S\,\Theta_2\\Hg\end{matrix}\right\}\Theta_2$.—This salt is prepared by acting upon metallic mercury with an excess of boiling sulphuric acid. The salt is deposited under the form of a crystalline powder or in little needle-like forms. Water decomposes it and forms a basic salt known as turpeth mineral. If this latter substance is boiled for a long time in water, it loses the elements of the sulphuric anhydride and leaves a residue of bioxide of mercury. The formula for turpeth mineral is

$$\left.\begin{matrix} & S\,\Theta_2\\ \left(\begin{matrix}Hg\\Hg\\Hg\end{matrix}\right. & \begin{matrix}\Theta\\\Theta\end{matrix}\end{matrix}\right\}\Theta_2$$

Photochloride of Mercury (calomel).—Protochloride of mercury may be obtained by triturating the bichloride with mercury, or by distilling the minimum sulphate of mercury with chloride of sodium.

$$1.\qquad \underset{\text{Bichloride of mercury.}}{Hg\,Cl_2} + \underset{\text{Mercury.}}{Hg} = \underset{\text{Protochloride of mercury.}}{Hg_2\,Cl_2}$$

$$2.\qquad \underset{\text{Minimum sulphate of mercury.}}{\left.\begin{matrix}S\Theta_2\\ H_2\end{matrix}\right\}\Theta_2} + \underset{\text{Chloride of sodium.}}{2\left(\left.\begin{matrix}Na\\ Cl\end{matrix}\right\}\right)} = \underset{\text{Sulphate of soda.}}{\left.\begin{matrix}S\Theta_2\\ Na_2\end{matrix}\right\}\Theta_2} + \underset{\text{Mercurous chloride.}}{Hg_2\,Cl_2}$$

This salt may also be prepared by precipitating a minimum soluble salt of mercury by hydrochloric acid, or by a chloride in solution in water.

$$\underset{\text{Mercurous nitrate.}}{Hg_2\left\{\begin{matrix}\Theta N\Theta_2\\ \Theta N\Theta_2\end{matrix}\right.} + \underset{\text{Hydrochloric acid.}}{2\left(\left.\begin{matrix}H\\ Cl\end{matrix}\right\}\right)} = \underset{\text{Mercurous chloride.}}{Hg_2\,Cl_2} + \underset{\text{Nitric acid.}}{2\,N\,H\,\Theta_3}$$

The chloride thrown down is known in pharmacy as white precipitate, and is the most active. That prepared by the other two processes is termed calomel. If distilled, and its vapour received in an apparatus full of air, this fluid intervenes between the molecules at the moment of solidification, and a powder is thrown down known as steam calomel, because steam was formerly employed in this operation instead of air. Calomel thus prepared is weaker in its action than the white precipitate, but stronger than that obtained by subliming the protochloride under the form of solid masses and afterwards pulverizing it.

Mercurous chloride crystallizes by sublimation in prisms of the second order. The protochloride is white; when exposed to the light, it is decomposed into mercury and sublimate.

$$\underset{\text{Protochloride of mercury.}}{Hg_2\,Cl_2} = \underset{\text{Corrosive sublimate.}}{Hg\,Cl_2} + \underset{\text{Mercury.}}{Hg}$$

A similar decomposition appears to take place when it is vaporized. Calomel is, indeed, one of those substances whose vaporous density seems to form an exception to Ampère's law, this density being only half what it ought to be. This anomaly is explained, as in the case of chloride of ammonia, by admitting the occurrence of dissociation. Calomel is insoluble in water, alcohol, and ether. Nitric and hydrochloric acid attack it. With the former of these acids, it is converted into a compound of bichloride and nitrate; with the latter it is converted wholly into bichloride. When heated with the alkaline chlorides, calomel is transformed into corrosive sublimate. This action may take place at about 100°, if organic matters intervene, especially in the presence of acids and the oxygen of the air. This fact is of great importance; for as the stomach always contains acids, air and organic matters, if alkaline chlorides were administered at the same time as calomel, sublimate would be formed and the patient poisoned. When in contact with ammonia, calomel is converted into a black substance answering the formula

$$\left.\begin{matrix}Hg_2\\ Hg_2\\ H_4\end{matrix}\right\}N_2\,Cl_2 = Hg_4\,N_2\,H_4,\,Cl_2.$$

Protobromide of Mercury, $Hg_2\,Br_2$.—This salt is prepared in the same manner as the protochloride, and it possesses similar properties. No use whatever is made of it.

Protoiodide of Mercury, $Hg_2\,I_2$.—This substance may be obtained by precipitating mercurous nitrate by iodide of potassium.

$$\underset{\text{Mercurous nitrate.}}{Hg_2\left\{\begin{matrix}\Theta N\Theta_2\\ \Theta N\Theta_2\end{matrix}\right.} + \underset{\text{Iodide of potassium.}}{2\left(\left.\begin{matrix}K\\ I\end{matrix}\right\}\right)} = \underset{\text{Nitrate of potassa.}}{2\left(\left.\begin{matrix}N\Theta_2\\ K\end{matrix}\right\}\Theta\right)} + \underset{\text{Protoiodide of mercury.}}{Hg_2\,I_2}$$

But, as the mercurous nitrate is always acid, iodine is liberated during the reaction, and this iodine converts a portion of the protoiodide into biiodide. Consequently, if it be required to obtain pure protoiodide, it is better to triturate under alcohol 200 parts of mercury with 127 parts of iodine. The protoiodide is of a greenish-yellow colour. When heated suddenly, it becomes volatilized without being decomposed; but when heated slowly, it yields up half of its metal and passes into the state of biiodide. It is insoluble in water, alcohol, and ether; when heated with the alkaline iodides it gives mercury, while at the same time biiodide is formed, to which a double iodide succeeds. The protoiodide of mercury is the mercurial compound that serves as a base to most of the pharmaceutical preparations of mercury intended for internal application.

Subsulphide of Mercury, $Hg_2\,S$.—This very unstable substance is produced when a soluble mercurous salt is precipitated by hydrosulphuric acid.

$$\underset{\text{Murcurous nitrate.}}{Hg_2\left\{\begin{matrix}\Theta N\Theta_2\\ \Theta N\Theta_2\end{matrix}\right.} + \underset{\text{Hydrosulphuric acid.}}{\left.\begin{matrix}H\\ H\end{matrix}\right\}S} = \underset{\text{Nitric acid.}}{2\left(\left.\begin{matrix}N\Theta_2\\ H\end{matrix}\right\}\Theta\right)} + \underset{\text{Mercurous sulphide.}}{Hg_2\,S}$$

But it is almost immediately decomposed into metallic mercury and protosulphide.

$$\underset{\text{Subsulphide of mercury.}}{Hg_2\,S} = \underset{\text{Mercury.}}{Hg} + \underset{\text{Protosulphide of mercury.}}{Hg\,S}$$

Subsulphide of mercury is black.

Suboxide of Mercury, $Hg_2\,\Theta$.—This suboxide is a black powder, and is obtained by precipitating minimum nitrate of mercury by potassa.

$$\underset{\text{Minimum nitrate of mercury.}}{Hg_2\left\{\begin{matrix}\Theta N\Theta_2\\ \Theta N\Theta_2\end{matrix}\right.} + \underset{\text{Potassa.}}{2\left(\left.\begin{matrix}K\\ H\end{matrix}\right\}\Theta\right)} = \underset{\text{Nitrate of potassa.}}{2\left(\left.\begin{matrix}N\Theta_2\\ K\end{matrix}\right\}\Theta\right)} + \underset{\text{Water.}}{\left.\begin{matrix}H\\ H\end{matrix}\right\}\Theta} + \underset{\text{Suboxide of mercury.}}{Hg_2\,S}$$

It is as unstable as the subsulphide, and is decomposed in the same manner as the latter, namely, into mercury and protoxide.

$$\underset{\text{Suboxide of mercury.}}{Hg_2\Theta} = \underset{\text{Protoxide of mercury.}}{Hg\Theta} + \underset{\text{Mercury.}}{Hg}$$

Mercurous Nitrate, $\left.\begin{matrix}(N\Theta_2)_2'' \\ Hg_2\end{matrix}\right\}\Theta_2$.—This substance is prepared by dissolving mercury in an excess of dilute nitric acid. In a little time, beautiful crystals are deposited, the form of which is derived from an oblique rhomboidal prism. This salt dissolves in a very small quantity of water; if the water is in excess, a basic salt is thrown down, and a portion of the neutral salt remains dissolved by the nitric acid which has been liberated. When cold dilute nitric acid is allowed to stand with a great excess of mercury, a condensed salt is formed existing as large colourless crystals; the formula of this salt is;—

$$\begin{matrix} & \Theta N \Theta_2 \\ Hg_2 & \} \; \Theta \\ Hg_2 & \\ Hg_2 & \} \; \Theta \\ & \Theta N \Theta_2 \end{matrix}$$

Minimum Sulphate of Mercury, $\left.\begin{matrix}S\Theta_2'' \\ Hg_2\end{matrix}\right\}\Theta_2$.—This salt is used only in the preparation of calomel. It is obtained by converting 8 parts of mercury into maximum sulphate, and afterwards triturating it with a quantity of metal equal to that already employed.

Analytic Reactions of the Mercurial Salts.—These salts are distinguished in analyses by the following characteristics;—

1. They give with hydrosulphuric acid a black precipitate insoluble in sulphide of ammonium and in boiling nitric acid.

2. A piece of copper determines a deposit of mercury, with which it amalgamates and assumes a white colour. Its original colour may be restored by heating it to vaporize the mercury. If the operation be performed so as to condense the vapours, liquid mercury may be obtained.

The following characteristics distinguish the maximum from the minimum salts of mercury;—

1. The caustic alkalies and ammonia produce in a solution of the minimum salts a black precipitate of oxide of mercury, which is almost instantaneously decomposed into mercury and protoxide of that metal.

$$\underset{\text{Suboxide of mercury.}}{Hg_2\Theta} = \underset{\text{Protoxide of mercury.}}{Hg\Theta} + \underset{\text{Mercury.}}{Hg}$$

The maximum salts give, on the contrary, with the alkalies, a yellow precipitate of protoxide stable at ordinary temperatures.

2. The soluble chlorides and hydrochloric acid determine the formation of a white precipitate of protochloride of mercury in the solution of minimum salts, but do not trouble that of the maximum salts.

3. The soluble iodides give with the minimum salts a greenish-yellow precipitate of protoiodide, whilst they produce with the maximum salts an orange-red precipitate, soluble in an excess of mercurial salt or alkaline iodide.

METALLOID. Fr., *Métalloïde*; Ger., *Metalloid*; Span., *Metalóide*.

See Metallurgy.

METALLURGY. Fr., *Métallurgie*; Ger., *Metallurgie*; Ital., *Metallurgia*; Span., *Metalurgia*.

Metallurgy is the art of working metals, comprehending the whole process of separating them from other matters in the ore, sometimes refining and parting them; in a more limited and usual sense, the operation of obtaining them from their ores.

Classification of the Metals.—Simple substances have been placed in a series so that each should be electro-positive relatively to the elements that precede, and electro-negative relatively to those which follow it. But as this series indicates neither the analogies nor the differences of properties possessed by the substances, it must be regarded as utterly irrational and unsuitable for purposes of study. Another division of substances is into metalloids and metals, these two classes being then subdivided. But the characters which serve to establish this division are far from being sufficient. The only natural classification would be to separate the simple substances into several families, each of which should contain those which have the same atomic character. Then, in each family, the substances might be arranged on the principle of the electrical seriation. Thus the first family should include the monatomic substances, fluorine, chlorine, bromine, iodine, hydrogen, silver, lithium, sodium, potassium, rubidium, cesium, and perhaps thallium, the place of which has not yet been determined with certainty. The former of these substances are electro-negative and the latter electro-positive.

We shall confine ourselves, however, to the classification which divides substances into metalloids and metals, adding to the metalloids certain elements hitherto reputed metals, but which, since the researches of Marignac, can no longer be separated from silicium. As to the subdivisions, we shall found these upon the atomic characteristics of the substances. Yet we shall make a few exceptions to this general rule, and in some cases class certain substances, not according to their absolute, but according to their most common atomic values, or, as some writers on chemistry aptly express it, their *quantivalence*. We shall proceed thus whenever the absolute atomic value manifests itself only in very rare instances, as, for example, in the cases of oxygen, sulphur, selenium, and tellurium, which are by nature tetratomic, but which almost always act as bivalents, and in the case of iodine, which in the immense majority of instances acts as monovalent, although it is triatomic. The following Table shows the distinguishing features of the metalloids and the metals;—

METALLOIDS.	METALS.
1. Several of the metalloids are gaseous.	There exists no gaseous metal.
2. The metalloids do not possess the lustre called metallic.	The metals possess a lustre called metallic.
3. The metalloids are bad conductors of heat and electricity.	The metals are good conductors of heat and electricity.
4. The metalloids have a relatively low specific gravity.	The metals have a relatively high specific gravity.
5. The oxides of the metalloids, on combining with water, usually produce acids, rarely bases.	The oxides of the metals, on combining with water, produce bases, rarely acids.
6. The metalloids are always electro-negative in the compounds which they form on uniting with the metals.	The metals are always electro-positive in the compounds which they form on uniting with the metalloids.

Subdivision of the Metalloids.—We shall divide the metalloids into five natural families; our classification is that of Dumas, slightly modified.

First Family.—This includes the monatomic metalloids, namely, chlorine, bromine, iodine, fluorine, and hydrogen.

Second Family.—This includes the diatomic metalloids, which are—oxygen, sulphur, selenium, and tellurium.

Third Family.—There is as yet only one metalloid in this family, namely, boron, which is triatomic.

Fourth Family.—Under this head we place the tetratomic metalloids, namely, silicium, zirconium, titanium, tin, and thorium.

Fifth Family.—This includes the pentatomic metalloids, which are — nitrogen, phosphorus, arsenic, antimony, bismuth, uranium, tantalum, and niobium.

Metals.—The number of metals which are regarded as useful is very limited. But as many which are of no direct practical use enter into combination with those which are generally useful, it is necessary to allude to some of the former, although their interest arises solely from their combination with others. In entering on this part of our work we are under the necessity of classifying the metals in some such manner as shall be useful to the smelter. The most rational classification appears to be founded upon the relation of metals to oxygen, supposing that the reduction of oxides is effected by means of carbon. The number of elements which form minerals is sixty-two, all of which have more or less influence in metallurgical operations. About fifty of these elements are considered metals by chemists, of which nearly half the number are found in such large quantities as to be of importance to the smelter. A large number of metals form slags, as oxides or other compounds, and are hardly known in their pure condition; still these are of high interest, not only because they form slags, but because these slags invariably impart a peculiar quality to the metal which is smelted under their influence. We may therefore divide the useful metals into two groups, the one which forms chiefly slags, and the other chiefly metals. To the first division belong, potassium, sodium, calcium, magnesium, manganese, aluminum, selenium, titanium, tellurium, arsenic, and chromium. The second group will then consist of zinc, cadmium, iron, nickel, cobalt, antimony, lead, bismuth, copper, mercury, silver, platinum, and the platinum metals, and gold.

Instead of describing the general qualities of metals, which we assume to be known by our readers, we insert the following Table, which furnishes all the information of this kind which is here required;—

Names.	Colour.	Specific gravity.	Fusibility.	Malleability.	Volatile at	Decomposing water.	Decomposes.
Potassium	grey-white	·865	136°	like wax, brittle at 32°	red heat	any temperature	all minerals
Sodium	„	·972	194°	malleable at 32°	„	„	do. except potassa compounds
Calcium	„	1·58		„	„	„	„
Magnesium	white	1·70	red heat	„	„	red heat	„
Manganese	grey-white	5·85	high heat	brittle, soft		any temperature	„
Aluminum	white	2·6	„	malleable		decomp. air at red h.	„
Selenium	red-brown	4·3	212°	very brittle	red heat	„	
Titanium	red	4·3	infusible	„		„	
Tellurium	grey-white	6·2	600°	„	red heat	„	
Arsenic	grey	5·67	400°	brittle	356°	any temperature	
Chromium	„	7·01	high heat	„		very permanent	
Zinc	white	7·	770°	malleable	white heat	at 490°	
Cadmium	„	8·6	550°	„	600°	burns in air	
Iron	„	7·78		„	very high h.	at any temperature	decompose the following
Nickel	„	8·2		„	„	„	„
Cobalt	grey	8·5		brittle	„	red heat	„
Antimony	white	6·7	932°	„	white heat	permanent	„
Lead	„	11·3	594°	malleable	„	„	„
Bismuth	white-yellow	9·8	476°	„	„	„	„
Copper	red	8·8	1996°	„	high heat	„	„
Mercury	white	13·5	39°	„	680°	„	„
Silver	„	10·4	2000°	„	high heat	very permanent	„
Platinum	blue-white	21·5	very high heat	very malleable	very high h.	„	„
Rhodium	grey-white	11·	melts in saltpetre	brittle	„	„	„
Iridium	„	21·80	high heat	malleable	„	„	„
Osminum	blue-black	10·	„		„	heated in air	„
Palladium	blue-white	11·8	„	„	„	high heat in air	„
Gold	yellow	19·4	2200°	very malleable	moderate h.	permanent	

All the metals, with few exceptions, are remarkable for a high and peculiar lustre; they conduct heat and electricity better than any other substance. They are considered as opaque, but this can be no absolute property, for all metals are porous, and consequently must transmit light when in a body sufficiently thin. The affinity of metals for oxygen is remarkably strong; but under certain conditions, the oxygen is removed by chlorine, sulphur, and other substances. The compounds which are of interest to the metallurgist, are the oxides, carburets, sulphurets, phosphurets, chlorides, arseniurets, silicides, but the salts of the metallic oxides are of the most interest, such as silicates, carbonates, phosphates, chlorides.

Affinity for Oxygen.—Metals are, generally speaking, combustible. They generate heat under the same laws as carbon and hydrogen. It makes no difference in the quantity of heat generated, whether we burn zinc with a pound of oxygen, or carbon with the same weight of oxygen. But, while potassium burns on water, gold must be combined with chlorine before it can be oxidized, that is, its affinity is so feeble, or its body so compact, that it must be dissolved, or divided, into the most minute atoms before it can be combined with oxygen. The metals never combine with any oxidized substance, and least of all with their own oxides, however determined their affinity for oxygen may be. To this rule the exceptions are very few. This is one of the most important peculiarities of metals; and it is the best auxiliary to the smelter. This want of affinity for other substances is the reason why fluid metals appear with a convex surface. The same property is strikingly shown in the refining of precious metals on the cupel; it is the cause of fibres in wrought iron. The form under which metals most readily oxidize is of high interest; but as it depends upon many circumstances besides affinity, we will point out the means by which they are deprived of oxygen, from which the reverse may be deduced. Metals which are deprived of their oxygen by the mere application of heat, are, mercury, silver, gold, platinum, palladium, rhodium, iridium, and osmium; for this reason these are termed precious metals.

Those metals which retain their oxygen at high temperatures, and in fact cannot be reduced by heat only, we shall proceed to enumerate. Of the number, the alkaline metals, potassium, sodium, calcium, and magnesium, decompose water at any temperature and retain their oxygen at any heat, while their oxides form alkalies in all cases.

Aluminum and similar metals retain their oxygen, but do not decompose water except at high heats, and form either alkalies or acids.

Nickel, cobalt, iron, tin, cadmium, zinc, and manganese, decompose water at a red heat, and their oxides form either alkalies or acids, according to the matter present, or their state of oxidation.

Lead, copper, titanium, bismuth, uranium, and tellurium do not form acids at high heats, and do not decompose water at any heat; neither does antimony, chromium, or arsenic, but when oxidized, they form invariably acids at melting heats.

The combinations of oxygen and metal take place in certain definite proportions, and, so far as relates to most of the metals, in various definite quantities. There is only one oxide of aluminum, but there are three of iron, which interest us. The protoxide of iron is a strong alkali, the magnetic oxide a feeble alkali, and the peroxide is more of an acid than an alkali. Peroxide and protoxide of iron, both infusible by themselves, form a fusible slag, or glass. Arsenic forms in all stages of oxidation an acid, which never melts together with another acid, or a highly-oxidized metal. The electro positive or negative character of an oxide is, however, no condition required for its fusibility; for litharge and lime, both strong alkalies, melt together and form slag. But it is always a requisite condition that one of the constituents must be fusible, in which the other is merely suspended. This chemical relation is by no means limited, that is, one and the same substance is not always, nor in all relations, of the same character. The oxides of iron are always alkalies with silex, but they are acids in relation to oxide of lead. Alumina is an alkali in the presence of silex, but an acid when in contact with the alkalies proper. The study of the metallurgist must be directed to these chemical relations, and chiefly also to the degree of fusibility of these compounds, and the relation which they bear to the metal to be produced under their influence. As a rule, we may state that the compounds of single equivalents of metals and oxygen always constitute a base, or alkali, and that any more oxygen destroys that property.

Hydrated Oxides.—The oxides also combine in certain proportions with water, and form definite compounds, called hydrates. These combinations are not only of interest so far as they form the most porous and best kinds of ore, but the tenacity with which water adheres to some of the hydrates is remarkable. Potash, clay, and silex retain their water at an almost red heat, and the first may be actually melted without losing all its water.

The degree of affinity of oxygen for metal is the strongest, and is most difficult to destroy at a medium state of oxidation between the highest and lowest. Protoxide of tin is easily converted into metal, so is peroxide, but the sesquioxide, a combination between, or of, the two, cannot well be reduced to metal without evaporating the largest part of the metal. In practical operations we always endeavour to smelt the highest oxides, and convert the ores into them, in case they are not naturally in that state. The reasons for this are, that in reviving metals from their ores, it is not only the object to remove the oxygen from the metal, but also to produce so high a heat as to melt the metal at the precise moment when the oxygen is removed. If only little oxygen is combined with the metal, it is evident that but little heat is produced; the metal may be in the proper form, but it cannot accumulate into a body, and the least amount of oxygen will oxidize it again. If the quantity of oxygen is large, a proportionate amount of carbon will be consumed, and the heat will be higher than when there is less oxygen with the same amount of metal; the metal will now melt, agglutinate, and in that form resist the influence of oxygen successfully. This law is apparent in most cases when smelting is done on a large scale, but particularly so in smelting refractory metals,—such as iron, manganese, chromium, and others. Lead may be smelted in either form, because the metal is very fusible, but less lead is evaporated in smelting minium than litharge, or galena.

Affinity for Chlorine.—Chlorine has a peculiar tendency to induce metals to crystallize; it causes fluidity and brittleness. The affinity of chlorine for metal surpasses that of oxygen, and drives

out the latter in all instances. It cannot be removed by carbon, but it sometimes may be by hydrogen, as in the case of gold, silver, copper, lead, and mercury. The energetic connection between chlorine and metals would be an impediment to working ore, in which even a small amount of it was present; but all chlorides are extremely volatile and easily driven off. Still there is always an indication of the presence of chlorine in those metals which have been smelted from ores containing it. Chlorine removes all other matter from metals, when the latter are in a state of fusion; carbon, sulphur, phosphorus, and other volatile matter is driven off by it, and, if the heat is continued, the chlorine itself escapes at last with a portion of the metal. This is the case when only a minute amount of it is present. It is therefore one of the most powerful means of purifying metals. Lead smelted from chlorides, or only from a mixture of chlorides and other ore, is always purer than that from oxides or sulphurets. The proper application of chlorides has a most beneficial influence on smelting and refining operations. Zinc does not combine very readily with iron, but if some chlorine is in it when melted, the operation is performed with the greatest ease. Chlorine has a remarkable tendency to combine with metals, and is particularly distinguished for removing oxygen from the peroxides; it therefore purifies the surfaces of melted metal, and causes those in an alloy to unite closely. This is not only the case with different metals, but also with any one in which there is chlorine.

Chlorine is not decomposed by any heat, or other means; it is therefore always present in its pure and proper form, and we may depend upon removing it finally by the continuation of heat only. All metals which have been smelted under the influence of chlorine are remarkably inclined to oxidize so long as it is not entirely removed. It is a harmless substance to the metals; and, as it is a powerful means of fluxing ore and slags, and causing metal to be fluid, its use ought to be more extended than it is at present. So long as volatile substances are combined with a metal, very little or no chlorine escapes; but after sulphur, phosphorus, and similar matter is driven off by it, chlorine itself escapes—first with arsenic, then tin, antimony, mercury, zinc, and iron. We may therefore regulate the refining of metals under the influence of chlorine, according to the volatile character of the substance to be removed; observing due regard to the degree of affinity between chlorine and that substance. Some chlorides escape in their proper form, such as those of arsenic, tin, and antimony; others are decomposed so soon as they are liberated and atmospheric air or steam has access, as chloride of iron, aluminum, and silex, which are converted into oxides and hydrochloric acid. All evaporated chlorides may be recovered by condensation; they are precipitated at a temperature a little higher than that at which steam condenses.

Iodides, bromides, and fluorides, are similar in operation to chlorides; but as they are not so plentifully met with as the latter they are of little interest to the smelter.

Sulphurets.—All metals combine more or less vividly with sulphur, which combination is, in all cases, destroyed by oxygen or chlorine, with the assistance of heat. Sulphurets are formed when sulphur is brought in contact with hot metal, provided no oxygen or chlorine is present. When oxides are heated with sulphur which so far predominates as to absorb all the oxygen in forming sulphurous acid, the remaining sulphur will combine with the metal. When sulphates are heated in the presence of carbon or hydrogen, the oxygen of the sulphuric acid is abstracted, and sulphurets remain. Sulphuretted hydrogen, when conducted over oxides, or over red-hot metal, forms sulphurets. A hot, or fluid metal, which contains only a small amount of chlorine, does not absorb sulphur. The chemical relation of sulphur to metal is similar, in respect to quantity, to that of oxygen; that is, the number and equivalent composition of the sulphurets correspond with the number and equivalent of the oxides of the respective metals. Sulphur causes metals to be more fluid, and brittle when cold, and, in most instances, imparts to them a pasty condition which impairs their ductility when hot. A large quantity of sulphur causes a low degree of fusibility in metals, which is shown most distinctly in the sulphurets of antimony, lead, copper, and iron. This fusibility decreases more rapidly than the evaporation of sulphur. Iron pyrites melt at a very low red heat; but when the quantity of sulphur is reduced by evaporation to half the original quantity, it requires a strong white heat to melt the sulphuret. This fusibility of the sulphurets is in many instances judiciously applied in the formation of a fluid slag. For the removal of sulphur from metals, the presence of free oxygen or chlorine is required; it is therefore of no avail to melt metal which is adulterated with sulphur, under an alkaline slag, because no slag will absorb sulphur from a metal until it has itself been converted into sulphuric acid. Sulphur cannot be removed entirely when carbon, hydrogen, or any reducing agent is present; it requires an oxidizing influence, and a thorough exposure of the metal to oxygen. Sulphurets may be reduced by means of metals which show a stronger affinity for sulphur than those in combination with it. The sulphurets of copper, lead, antimony, and others may be reduced by iron, but we never thus obtain pure metals, the newly-formed metal is either adulterated by the absorbent, or by sulphur. Instead of metals themselves we may employ the oxides, particularly the peroxides, finely powdered and mixed with carbon. Sulphurets of antimony, silver, and bismuth, may be reduced by means of hydrogen, but no other metals.

Phosphurets.—Phosphorus combines readily with most of the metals, and adheres tenaciously to them. The combination is readily formed when phosphates—the form in which it is generally found in the ores—are heated in the presence of carbon; and, as the latter is always used in smelting operations, we may reasonably expect phosphorus in any metal which is smelted in the presence of phosphoric acid, and carbon or hydrogen. Therefore the presence of bones, or bone ashes, in an ore or in a slag, will cause the metal to contain phosphorus. The best means for forming a phosphuret is to heat a phosphate in the presence of carbon. Phosphorus is more easily oxidized than sulphur, and combines in this condition readily with alkalies and alkaline earths; we may therefore by these means remove phosphorus. It also causes metals to be very fusible, more so than any other substance, but disposes them to be brittle when cold.

Carburets.—Carbon has only a feeble affinity for metals, and cannot readily be combined with them. But in most cases the metals when reduced from porous oxides in the presence of an excess

of carbon, absorb some of it, and condense it in their pores. It is doubtful if a chemical combination is formed; still there are indications of legitimate compounds under certain conditions. The best means of forming carburets are the carbonates and oxalates heated in the presence of carbon. The crude iron obtained from the smelting of sparry iron ore may be considered a real carburet of iron. Carbonate of lead, when reduced by means of carbon, forms also a carburet; but this is less distinct than that of iron. In consequence of the faint affinity of carbon for the metals, they are generally very brittle when the amount of it is large. But when a small amount only is mixed mechanically with metal, as is the case in grey cast iron, its strength is not much impaired. The combinations of carbon and metal are more fusible than pure metals; and as carbon is easily removed from metal by oxygen, it is one of the best means to cause metals to be fusible.

See ALLOYS. ATOMIC WEIGHTS. And articles on the various metals.

Books on Metallurgy;—Phillips (J. A.), 'Manual of Metallurgy,' crown 8vo, cloth, 1852. 'Practical Treatise on Metallurgy,' from the last German edition of Professor Kerl's 'Metallurgy,' by W. Crookes and E. Röhrig, 3 vols. 8vo, 1860–70. 'Traité Complet de Metallurgie,' par le Dr. J. Percy, traduit par MM. Petitgand et Ronna, 5 vols. royal, 1864–67. Makin's (G. H.), 'Manual of Metallurgy,' crown 8vo, 1873. Overman's 'Metallurgy,' 8vo, New York.

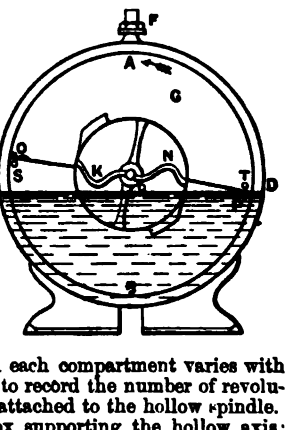
METER. FR., *Compteur*; GER., *Messapparat*; ITAL., *Misuratore*; SPAN., *Metros*.

Wet Gas Meters.—For many years after the first invention of gas it was impossible to estimate the quantity burnt by the consumer, or passed through any pipe, except by the size and number of the burners and length of time of ignition. These points were therefore made the subject of a contract between the makers and the consumers, but the result was unsatisfactory, it being impossible to check the latter when they burnt more gas than agreed upon in the contract. In order that gas-lighting might become universally adopted in towns, it became necessary that the quantity of gas burnt should be accurately measured.

Solids and liquids can be handled and seen, but gas cannot, and is very light, therefore it is more difficult to measure; besides, a continuous record is necessary. A small gasholder will measure a certain quantity of gas or air with the greatest possible accuracy, but it keeps no record, and could not be used without impeding the flow of gas in the passage from the mains to the burners.

In 1815 the first gas meter was made by S. Clegg. In his specification of that date he describes two different kinds of meter, both worked by the light pressure of the gas as it flows from the mains. One of these meters was excessively complicated in construction, but the other, on a simpler plan, is shown in Fig. 5854. A B is a cylinder or drum, revolving on a hollow axis C, and contained in a case D E. The inlet for the gas is through the hollow axis C, the outlet being at F. The inlet communicates with two semicircular chambers, by means of two bent tubes K, N. The two chambers are separated from each other by two partitions, in which are placed two valves O, P, in order to allow a free passage of the water from one compartment to the other during the revolution of the cylinder, which acts as follows;—In the position of the drum, as shown in the figure, the gas entering through the hollow axis C passes through the bent tube N into the compartment with the valve P, which closes as the partition rises out of the water. The gas in the same compartment under the valve O escapes through the hole S into the case, and passes away to the burners through the outlet F. The gas cannot pass through the bent tube K, as the small trough above it has taken up a little water, and at the same time that the outlet-hole T rises above the liquid the little trough discharges its water into the pipe K, which is thus sealed. As soon as the valve O enters the water the gas in the compartment G is discharged through the hole T into the case; thus one compartment is always filling and another always emptying. The quantity of gas required to fill each compartment varies with the size of the drum, and this being correctly determined it is easy to record the number of revolutions made by the drum by means of a suitable train of wheelwork attached to the hollow spindle.

5854.



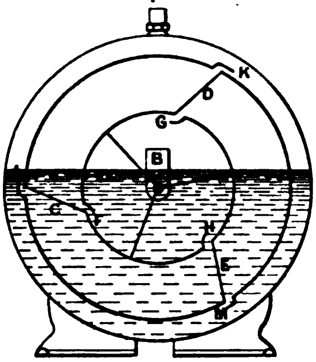
One defect of this machine was the friction of the stuffing box supporting the hollow axis; another that the valves O, P, soon got out of order. The sudden sealing of the tubes by the water falling from the small troughs caused oscillation in the lights; but with all its faults this early meter places the name of Samuel Clegg among the first who contributed to the advancement of the science of gas-lighting.

In the year 1824 Sir William Congreve invented a meter, in which he registered the flow of gas through a pipe or cock where the pressure is uniform, by registering the length of time the tap was open. For this purpose he applied to each cock or pipe a small clock movement, which was started by opening the cock, and stopped by shutting it. The dial indicated the number of hours the cock was open. This inferential measurement was far superior to the old contract system, but did not prove an accurate measurer of the quantity of gas burnt.

Figs. 5855, 5856, show the interior of John Malam's meter, which consisted, like Clegg's, of a drum revolving upon an axis in an outer case. The axis, instead of being hollow and working at one end through a stuffing box, is mounted, as shown in Fig 5856. The gas entering at A, passes through the bent tube A B, into the measuring drum. This drum is divided into compartments, each having an inlet space in its inner side and an outlet opening on its periphery. The inlet to the compartment D E, Fig. 5855, is at G, and the outlet at M The inlet and outlet to the compartment C E are respectively at L and N, and to the compartment C D at F and K. The gas, entering by the pipe A B, passes through G into that portion of the compartment D E which is above the water, and acts like a wedge, pressing against D so as to drive the drum round in the

direction of the arrow. While this is being done the gas in that part of the compartment C D which is above the water is expelled at the outlet K, and escapes by the outlet-pipe of the meter. The quantity of gas required to force the drum to make a complete revolution being accurately ascertained, the number of revolutions is indicated by the usual train of wheelwork and dials, and the quantity of gas passing thus registered.

5855.



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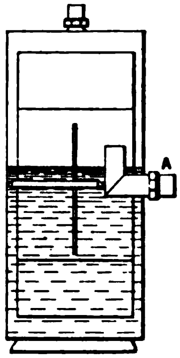

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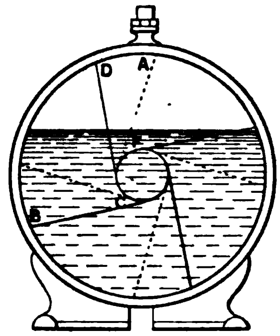
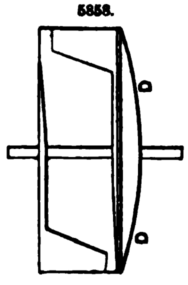
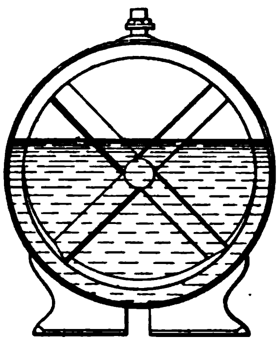


Samuel Crosley further improved Clegg's meter. A front view of the drum of Crosley's meter is shown in Fig. 5857, but without the hollow cover which enclosed this part. Fig. 5858 is a plan of the drum, with that part of the body removed which covers one of the compartments; the hollow cover is shown at D D. Fig. 5859 is a section showing the four interior partitions. The principle is the same in this drum as in that of Malam. The drum is divided into compartments, the partitions of which are, however, not at right angles with the front and back plates of the drum, but are placed at an angle as represented in Fig. 5859. By this modification the drum in revolving cuts the water, instead of allowing the flat sides of the partitions to beat against the liquid. There is therefore much less resistance to the drum in its passage through the water; it revolves with greater freedom, and the resistance is at all times equal, which is absolutely necessary, or the lights would burn unsteadily. There is also space in the centre of the drum for the free passage of the water from one compartment to another. The inlet and outlet spaces were placed by Crosley, the

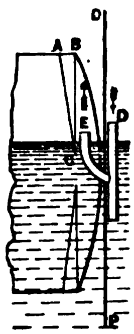
5858.



5859.



5860.



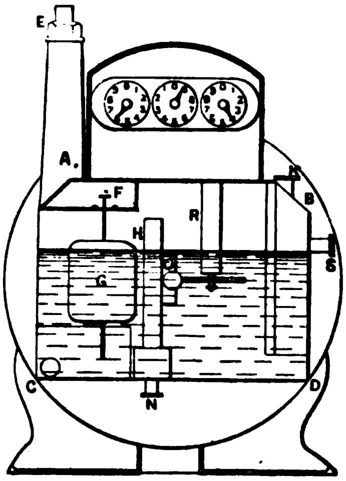
one in front of the drum under the hollow cover, and the other at the back of the drum. These have to be so arranged that there is no free passage through the meter without moving it. The spaces are therefore arranged as in Fig. 5857, in which the radial lines D, C, F, G, and others, show the position of the slits through which the gas passes to the compartments behind. The slits are shown in section at A, B, C, Fig. 5860. The gas is introduced into these four inlet passages to the compartments by means of the bent tube or spout E D, Fig. 5860. The water-level must always be above the hole in the hollow cover through which the bent tube is passed, otherwise gas would pass through the meter without moving it. The drum is now universally in use in wet meters, although in other parts of the machine there are many variations in detail, intended principally to regulate the height of the water-level, on which the whole accuracy of the instrument depends. The drum is difficult to draw and explain in section, as all the plates in it vary much in their planes, and are placed diagonally in respect to each other. But the drums are simple in construction, and cut the water smoothly. Their sizes are calculated according to the number of lights the finished meters are intended to supply. In the trade the meters are named according to the number of burners they are intended to feed; thus they are designated five-light meters, or ten-light meters, and so on. The lights thus alluded to are always understood to be those produced by burners which each pass 6 cub. ft. of gas an hour; thus a ten-light meter will supply ten burners, each consuming 6 ft. of gas an hour, or twenty burners each consuming only 3 cub. ft. an hour. The smaller-sized

meters are made to pass the required quantity of gas with about 150 revolutions an hour, but the larger ones decrease in the number of revolutions as they increase in size.

The accuracy of registration of the meter depends principally upon the height of the water-line. Fig. 5859 shows that when the water-line is high it passes less gas a revolution, but when it is low more gas. The index can only show the number of revolutions of the drum, but not whether the drum holds the proper proportions of water and gas. It therefore becomes a matter of great importance to gas manufacturers and consumers that the water in the meter should be kept at the proper level. The arrangement adopted by Crosley, also by William Parkinson, and by others, is shown in Fig. 5861.

In fact all the more recent modifications in the wet meter include the drum already described, but vary in the plan adopted to keep the water at the true level. In Crosley's arrangement, in front of the cylindrical case containing the drum is fixed a square box, A B C D, Fig. 5861. The gas enters at F, and passes into the square frame at the corner A. In this corner of the square frame is fixed a valve F, through which the gas passes. Below the water-line there is an opening from this square frame into the drum case behind, so that the water finds the same level in both. The valve F is worked by a float G below it. This is balanced so that when, by evaporation or otherwise, the water-level falls below a given point, the float shuts the valve and cuts off the gas. Of course, then, the lights go out, and more water must be put in the meter. The gas fills the upper part of the square frame, then passes down the pipe H, and through a branch from it into the drum, Fig. 5860, where the line O P represents the partition between the drum case and the square frame.

5861.



The plug K, Fig. 5861, opens to allow water to be put in the meter, whilst the plug N opens to draw off any water that may rise above H. This diagram shows the connection between the drum-shaft and the registering index. On the end of the drum-shaft is placed a worm O, working into a cog-wheel P, which, by means of a spindle through the tube R, turns the index at the top. In a three-light meter the measuring drum revolves eight times to a cubic foot; the wheel on the spindle has forty teeth, consequently the latter makes one revolution for every 5 ft. of gas passed. A worm on the top of the spindle works into a wheel of twenty teeth, which consequently revolves once with every 100 cub. ft.; on this there is a pinion of six working into a wheel of sixty teeth, and to the axle of this wheel is fixed the first hand on the dials, which consequently makes a complete revolution for every 1000 ft of gas passed through the meter. The side plug S is for adjusting the correct water-line of the meter, and when the water in the meter is higher than this plug the instrument registers against the consumer, but when below it is in his favour. To get the right level the meter should first be filled with water, and then the plug S opened till no more water will run out through it, when the water-line will be the true one.

The defect of this meter is the power it places in the hands of unprincipled people to tamper with it by altering the water-level. This has been done by introducing the short end of a siphon into the plug K, and drawing off some of the water. Nevertheless both gas manufacturers and consumers had full power over the plug S, which tells the truth of the case, so the gas companies found it necessary to appoint inspectors to go round frequently and examine the state of the meters.

In 1853 J. Z. Kay introduced a hydraulic valve meter, in which he dispensed with the ordinary float and valve already described, and substituted a hydraulic seal. This was placed on the back of the meter—which otherwise was of Crosley's construction. When the water had evaporated low enough to unseal a pipe at the back, gas was thereby admitted into a chamber in which water was held in suspension; accordingly sufficient water would flow out to bring that in the working part of the meter to its proper level.

It fixed the standard cubic foot for gas measurement, which previously was a variable bulk. It was accordingly settled that a cubic foot of water should equal 62·321 lbs. of distilled or rain water, weighed in air at a temperature of 62° Fahr., under a barometric pressure of 30 in.

A clause in the Sale of Gas Act orders that a meter shall be tested for capacity at $\frac{5}{10}$ the pressure whilst passing gas at the rate per hour stated thereon as its proper working speed, and if such meter can be made to vary more than 2 per cent. fast, or against the consumer, or more than 3 per cent. slow, or against the gas company, who consequently have the worst of the bargain, it shall not be stamped. The meter shown in Fig. 5861 could only comply with these requirements on two conditions—namely, first, that when the water-level was raised high enough for the meter to register 2 per cent. fast, it should overflow the pipe H; secondly, that if the water evaporated so as to register 3 per cent. slow, the float G should fall and close the valve. It was, however, found in practice that when the overflow pipe H and the float G was so adjusted, variations in pressure caused water very frequently to flow out of the meter through H to the annoyance of the consumer. The valve F was also liable to be closed. It was found that meters so adjusted worked well in low districts where there was little pressure, but badly in high districts with high pressure.

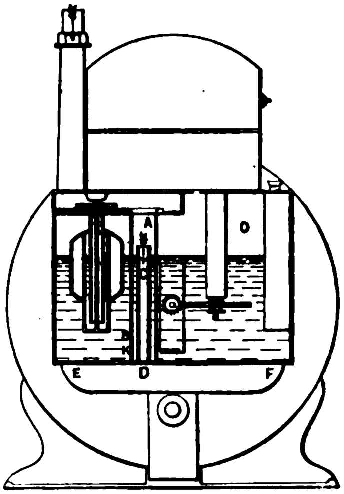
To meet this difficulty Pinchbeck devised a simple improvement, shown in Figs. 5862, 5863. The gas passes through the valve, as in Fig. 5861, but instead of filling the front chamber passes into the pipe A B, through the inner pipe G D into the waste-water box E F, then through the pipe F into the measuring drum. The improvement consists in reversing the action of the float, so that it

is raised instead of depressed by an increase of pressure. When the water-level in the meter oscillates through variation of pressure, very little gets into the waste chamber, as it has to pass through a small hole K at the bottom of the pipe A B. This meter fulfils all the requirements of the Act, and can be used in any situation and at any pressure. For many years meters have been constructed on this principle, and in large numbers, by W. Parkinson and Co., of London.

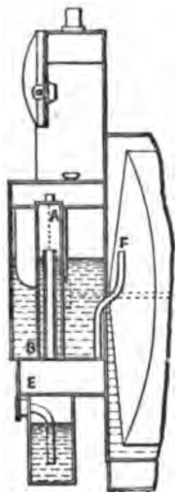
Wet meters, as at present sold, may be divided into three classes—the bird fountain, the mechanical spoon, and the compensating float. Crosley's bird-fountain meter was the first one. In 1858 Essen introduced a bird-fountain meter, shown in Figs. 5864, 5865. A is the front chamber, and B the waste box. D is the water-reservoir or supply-tank. This is supplied with water by means of the feed-pipe E, which is kept constantly sealed by the water in the surrounding closed pipe F. A sufficient opening is left at the top of the pipe F to allow water poured in at E to flow over the edge of the pipe F into th supply-tank D. An air-pipe G connects the front chambe. of the meter with the supply-tank. H is a pipe conveying water when necessary from the tank D into the front chamber A of the meter, to make up for loss by evaporation. The tank D is made air-tight, so no water can flow down H until air or gas enters the tank. When the water falls below its proper level, and below the lower mouth of the pipe G, gas will find its way up the pipe into the tank D, at the same time allowing water to fall through H to raise the water in the meter to its proper level again, and close the pipe G. The float K is fastened to the valve by a bent arm, and the gas enters the meter and passes through the valve and the meter the same as in Fig. 5861.

In 1855 Saunders and Donovan invented a meter, which is thus described in their specification;—We employ a

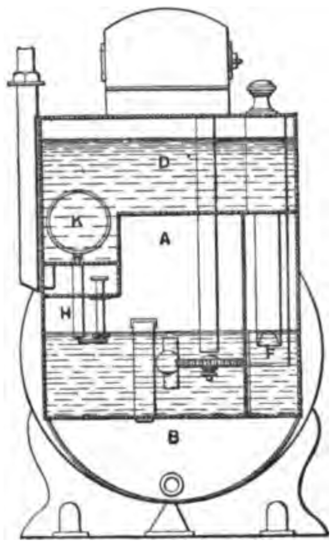
5862.



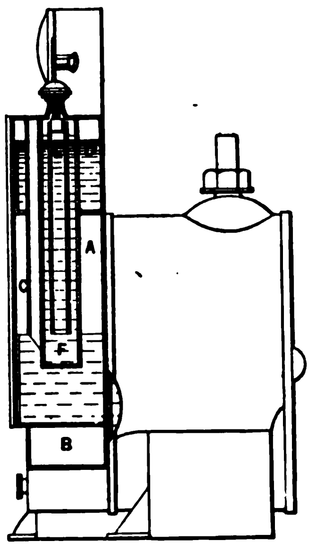
5863.



5864.



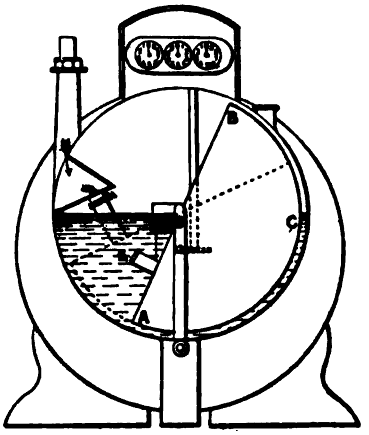
5865



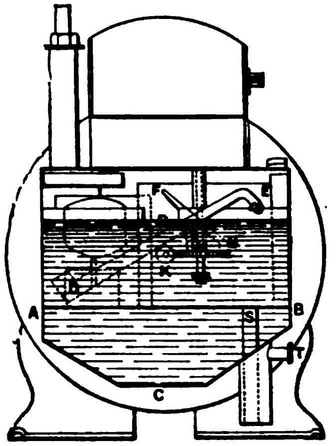
float of such weight in proportion to its volume, or otherwise so loaded and balanced, that it is capable of remaining stationary or in equilibrium whether a greater or lesser portion of it be immersed in the liquid, provided the level of the liquid remain the same. If, however, the level be raised by the addition of a certain volume of liquid, the float rises until a corresponding volume of the float has emerged from the liquid, and the level of the water has fallen to its proper place. If, on the other hand, the level be lowered by withdrawing a certain volume of liquid, a corresponding volume of the float becomes immersed and the level is again restored. One mode of arranging the apparatus consists in constructing the float of a semi-cylindrical or hemispherical form, turning upon a horizontal axis, mounted at or near the level of the liquid in the meter. If the float be made of half the weight of an equal volume of the liquid, or thereabouts, or if it be loaded or balanced to a corresponding amount, it will produce the desired effect; for when the float is in its highest position, with its flat side or diameter horizontal, it will balance itself on the axis; when the first quarter is immersed it will float up the second quarter, while the third and fourth quarters balance each other on the axis; and when the diameter is vertical, one half will be immersed and

will float up the other half. In Fig. 5866, A B C is the compensating float working on the axis D To this float is attached the valve E, which closes the passage for the gas into the meter when the float reaches or approaches its lowest position. The dotted lines show the position of the float when the valve is closed. This compensation is very accurate in its action. Meters upon this principle are manufactured by the Gas Meter Company, at their works, London, and elsewhere.

5866.



5867.



Another description of compensating meter is shown in Fig. 5867. In this there is a waste-water chamber of larger size than in other meters, and a spoon is made to rise and fall with the rotation of the drum, thus raising each time a small supply of water to take the place of that evaporated from the measuring part of the meter. All water thus raised, however, is not required for the purpose, and the surplus returns into the waste-water box through an opening at the proper level. In Fig. 5867, A B C is the waste-water chamber, and D E the spoon for raising the liquid out of it. The spoon is raised by means of the cam F G connected to the upright spindle working between the worm K on the shaft and the index. The lip P in the partition plate is the true water-line, and any excess of water in the meter which runs over this into the waste chamber A B C can be drawn off at the plug T. The gas enters the meter, passes into the measuring drum, and the index records the quantity consumed as usual. The water-level is always truly kept, and although the additional work given to the meter to perform theoretically adds to the friction, the effect is so small that it cannot be detected upon the lights or on the most delicate gauge.

Other methods of compensation have been suggested, but not largely adopted.

In all the wet meters it will be noticed that the original drum of Crosley has been retained, all the recent modifications being limited to the regulation of the water-level. The outer cases of wet meters are chiefly made of tin plate, which in some situations corrodes, although there are many instances of such meters working well continuously without repairs for twenty years. The liability to corrosion has induced many makers to manufacture meters in cast-iron cases. These, owing to improved modern methods of casting, can now be made so light that, while the durability of the meter is very greatly increased, there is little inconvenience on account of the weight.

Wet gas meters are sometimes made on a large scale, for the use of the gas companies at the works, and are then called station meters. Two station meters manufactured by Parkinson and Co., and fixed at the London Gas Works, Nine Elms, had a measuring drum each on Crosley's principle, which measures at each revolution 1000 cub. ft. of gas. The shaft in its centre is 6 in. in diameter. The drum is made of the best tin plate, each plate being riveted and soldered, and the whole built on a strong framework of cast-iron bosses, wrought-iron hoops, and angle-iron. Although the weight of this measuring drum is $3\frac{1}{2}$ tons, so delicately is it balanced, and so accurately made, that a pressure equal to a column of water $\frac{1}{10}$ in. high will cause it to move. Each meter is 16 ft. square, and weighs, without the measuring drum and interior work, about 24 tons. The whole complete and charged with water weighs about 100 tons. At a speed of 100 revolutions an hour these meters measure about 5,000,000 cub. ft. of gas a day. The inlet and outlet connections are 27 in. in diameter. The first hand of the index registers 1000 cub. ft. a revolution, and there are dials recording up to 10,000,000. In the centre of the index a contrivance called the tell-tale is fixed; it carries a disc with a circular card attached, which is made to rotate by the wheel-work. The minute hand of a clock fixed above the card carries a lever with a pencil fixed in the lower end, so that as the card revolves the rising and falling pencil makes marks upon it. By reference to this card it can always be seen what quantity of gas has been passed through the meter in each hour. It is usual at the gas-works to take the position of the index of the meter at very short intervals, in order to see that the making of gas is proceeding properly; but if this duty should be neglected a glance at the card would give warning. There is also placed in front of the meter an overflow arrangement to prevent too much water from being put into it, and two gauges to denote the pressure, so that the state of the meter can be seen at a glance.

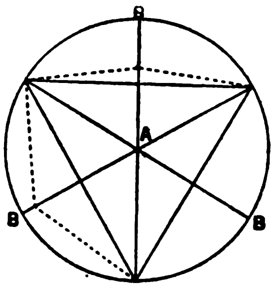
Certain defects in wet meters, more especially their liability to complete stoppage by frost, led to the construction and trial of the dry meter, in which, as its name implies, water is not used, but which has its own peculiar merits and faults.

In 1820 John Malam invented the first dry meter. It consisted of six bellows fitted into a case, each communicating with a hollow shaft, the gas being admitted in succession into each compartment by valves. This bellows action, governed by suitable valves, is the principle of all dry meters. The quantity of gas necessary to move the apparatus, so as to give one complete revolution to the shaft, being accurately ascertained, the capacity of the chambers is altered by a regulator till the shaft attached to the index causes the latter to indicate correctly.

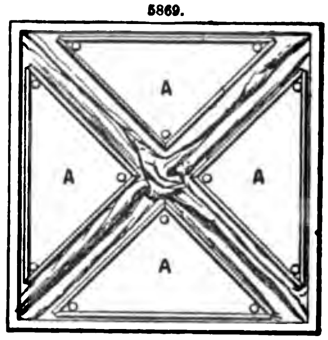
Malam's first dry meter, and several by other inventors which followed it, did not give satisfactory results. Of these, that by Sullivan, though never brought commercially into use, was founded on right principles. He divided the external chamber internally into two equal parts, which were each again divided by a flexible diaphragm or piston made of oiled silk, strengthened and protected at their centres by plates of metal. The gas is alternately introduced, by means of a sliding valve into one side of the diaphragm or the other. The oscillatory movement of the diaphragms works arms connected with an axis, and the motion is thence communicated to an index, through suitable arms, rods, and a crank wire. The flexible pistons should be so set in respect to each other that they shall not arrive at the end of their movement at the same time, but that one shall be in full action at the time that the other comes to the end of the stroke.

The earliest successful dry meter, and one largely in use at the present day, is that first made in 1842 by Defries and Taylor, working upon the same principles as the respiratory organs of the human body, by substituting diaphragms of leather for the lungs, and making them register their motion. Fig. 5868 is of N. Defries' first model of the flexible diaphragms, and represents a tin cylinder, closed at the bottom, and three radial partitions of tin, A, B, B, B, dividing the cylinder into three great fixed parts. Three flexible partitions of leather are shown in different positions by the dotted lines cut, whilst the fixed edges of the diaphragms are shown by the triangle. These leather partitions have a bellows movement, and when pressed inwards or outwards as far as they will go, assume the shape of a pyramid. With the flexible partitions the meter is thus divided into six chambers. The gas is allowed to enter all the different chambers in turn by a rotary valve of ingenious contrivance, so that when the chamber is expanded the gas is cut off from it, and allowed to pass into the chamber on the other side of the flexible partition, thus forcing the gas

5868.



5869.



out of the full chamber which has measured it into the delivery pipe. In this way all the chambers are filled and emptied in rotation, and the motion of the flexible partitions is communicated to the index, which thus is made to show the quantity of gas passing. The meter thus consists of three principal parts—the movable diaphragms, the valve, and the index.

As this meter is at present made by N. Defries and Co., of London, each leather diaphragm is first blocked into the shape of a pyramid, so as to allow of its having free angular motion. Each of the four triangular divisions thus made in the leather is covered with tin to protect and strengthen it, the only part of the leather left uncovered being that which is to act the part of a hinge, and therefore must be flexible. Fig. 5869 shows the diaphragm, with the triangular divisions A, A, A, A. All the diaphragms are steeped in oil for forty-eight hours, so as to make them perfectly flexible and gas-tight. A knuckle connects the four triangular pieces of metal to an upright shaft, which, in its turn, assists to move the valve and index.

The valve, which is rotary, is so constructed that the inlet-pipe passes down through its centre into a little chamber below the valve, whence it is permitted to pass through the valve into the different working chambers in turn. This valve, Figs. 5870, 5871, is coated with leather well oiled; this sweeps off any dirt which might otherwise interfere with its good action. The valve cannot lift so as to allow the gas to pass without being registered, and, being enclosed in a box, the gas cannot pass into the upper chamber of the meter, so as to exercise an injurious action on the gearing.

5870. 5871.

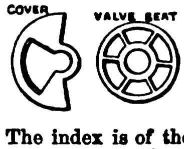
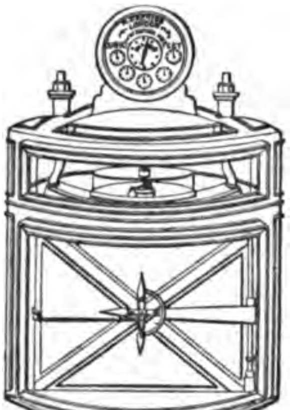


Fig. 5872 is a sectional diagram of the finished meter. The valve and its box, it will be seen, are enclosed in an upper chamber called the gallery. The index is of the usual tell-tale character, with decimal motion, and the action of the whole meter is regulated by a tangent-screw in the gallery, which lessens or increases the play of the movable diaphragms.

Another dry meter, now largely used, is founded upon an arrangement devised by Croll and Richards in 1844. Figs. 5873, 5874, show its internal parts. A A A A is a rectangular case divided into two equal parts by the partition B B. In each of these compartments there is a metal disc C C, each of which is connected to the central partition by a bellows ring of leather D D. Each side of the leather is firmly attached to a metal ring, in order that the whole may be completely air-tight.

The gas is admitted alternately to the interior and exterior of these diaphragms, by means of slide-valves placed in the compartment E E above. A plan of this compartment is shown in Fig. 5875,

5872.



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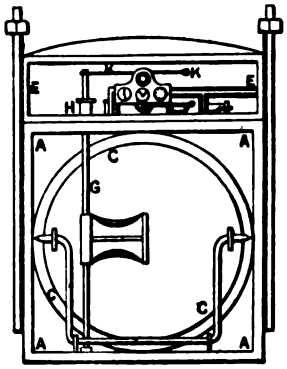
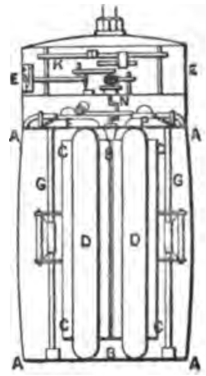
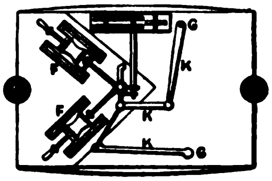


5874.



in which F, F, are the two slide-valves, with passages beneath communicating with the partitions below. The discs give motion to the two rods G, G, which pass through the stuffing boxes H. These rods, by means of the levers K, K, give motion to the crank N, to which the slide-valves are attached. The valves being properly set, the gas alternately fills each chamber, and as each disc reaches its limits of expansion or contraction the valves reverse the action, and so continuous motion is kept up. In this meter the leather has hardly anything to do with the measurement, and the capacity of each compartment can be calculated with great accuracy, by multiplying the area of the disc by the distance it has to travel. This meter is manufactured chiefly by the Gas Meter Company.

5875.



In the manufacture of the Defries' meters, they are tested for accuracy of measurement by means of gasometers. The gasometers are constructed to hold a certain amount of gas, from 10 ft. to 20 ft. of which is allowed to pass through each meter and then burnt. If the index on the meter shows the passage of exactly the amount of gas passed out of the gasometer, the meter registers correctly. If it does not the regulating tangent-screw is adjusted till accuracy is obtained. When this is the case the index is firmly fixed in its place, badges and labels are placed on the mèter, which is then sent to the Government office to be tested and certificated under the Sales of Gas Act, after which it is japanned and made ready for sale. Every meter before leaving the works is tested under a pressure of 20 in. of gas, which pumps it, and proves that all its parts are sound.

Water Meters.—When water is supplied in large quantities, as in irrigation works, it is usually measured by being passed through modules similar to those described in p. 2151. For measuring water in comparatively smaller quantities a meter is necessary.

The requisites of a good high-pressure water meter are;—First. It should register with sufficient accuracy for all practical purposes the quantity of water delivered at all the various degrees of pressure and rates of delivery.

Second. It should not destroy the onward pressure of the water. It should be capable of being fixed at the entrance of premises, so that it and all the pipes outside should be under the control of the water company, and all pipes within the premises under the control of the consumer. The company by this means secure payment for all water supplied, and the consumer has the risk of all waste; inasmuch as he pays for all the water that comes into his premises, he can make any number of connections convenient to himself without doing injustice to the company.

Third. It should be compact and adaptable to every situation.

Fourth. It should be simple and durable to the extent, as a rule, of not requiring repairs for a term of four or five years.

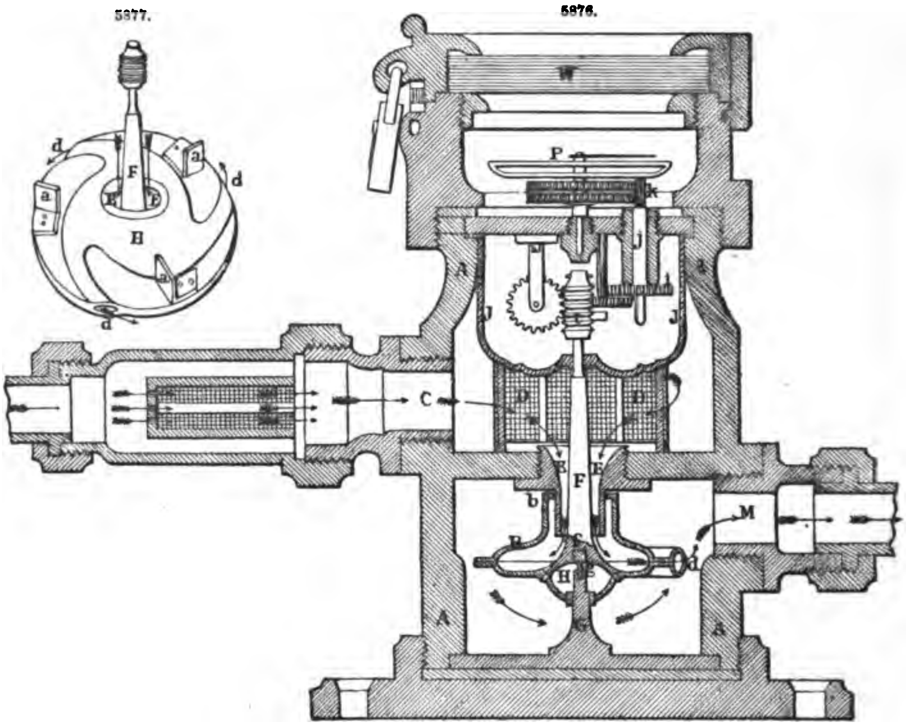
Fifth. It should be sufficiently low-priced, so as to place it within the reach of all classes of consumers.

These requisites are very well obtained in the meters invented by Joseph Adamson and C. W. Siemens, manufactured by Guest and Chrimes of Rotherham.

Fig. 5876 is a vertical section, and Fig. 5877 is a perspective view, of the measuring drum of Adamson and Siemens' water meter. The water enters the case A at the inlet C, and passes through a grating or wire gauze D, and through the neck or pipe E into the wheel B. Leakage between the pipe E and the wheel B is greatly diminished by making the upper part of the wheel with internal flanges *b*, *b*, which are not fitted tightly to the pipe E, but are just large enough to run freely round it. Any fluid which passes between the first collar and the pipe E forms eddies between the collars, and is thus prevented from escaping freely. F is the spindle of the wheel; it is furnished with a small steel thimble *f*, which rests on a pivot *g* fixed in the stud or pillar G,

fixed in the bottom of the case A; the pivot *g* is round at the top, and it is smaller than the thimble *f*, which can thus revolve or spin upon the pivot with very little friction. M is the outlet for the

5877. 5876.



measured water; H is an oil-cup, the bottom of which is turned up so as to approach very near to the top of the pivot, and has a central opening, which fits as close as possible to the upper part of the stud G, but turns freely around it. Any water which may leak into this oil-cup falls to the bottom or is thrown outward to its largest diameter by centrifugal force, and in either case it does not reach the pivot, but merely forces the oil up to it. The object of this arrangement is to prevent friction between the stud G and the oil-chamber, by keeping the wheel in its proper position by the thimble and pivot, while at the same time a small lateral motion is allowed, to enable the wheel to revolve on its true axis of gyration.

The wheel or revolving part B is made with two hollow arms, terminating in jets *d*, *d*, of a conical form, or of the form of the contracted vein. The wheel B is sometimes made in two parts, which are stamped to the required form and size, and furnished with flanges, which are joined on the horizontal line. Upon the wheel are placed vanes *a*, *a*, which present a considerable resistance to its motion. This resistance tends to equalize the indications of the meter for equal quantities of fluid passed through at different velocities. The wheel, or revolving part of the meter, and the case are so arranged that the wheel is submerged and surrounded by the fluid which is being measured. The spindle F is connected through the endless screw *t* and a train of wheels and endless screws contained in an oil-chamber J to a counter. The motion is thus reduced to the wheel *i*, whose spindle *j* passes through a cupped leather collar in the top of the case, and carries a pinion *k*, which drives the wheels turning the pointer P; W is a glass to protect the face of the index. These meters are in the first instance adjusted or graduated experimentally by passing a certain quantity of water through them at different velocities. The vanes are more or less bent, or portions are removed when necessary. The number of revolutions performed by the wheel in passing a certain quantity of water being ascertained, the wheels of the counter are proportioned, so that the pointers and dials may indicate gallons, cubic feet, or other units of volumė. Any number of meters may then be made of the same pattern and dimensions, and they will all indicate alike, or nearly so. Each one may be adjusted by varying the vanes or resistance to the wheel, or they may be used without adjustment, and their indications corrected by adding or subtracting their ascertained percentage of error.

METRIC SYSTEM.

By the metric system is meant the arrangement of weights and measures as used in France, and it is called metric because all the measures and weights have the French mètre for their basis.

The metric system comprises six kinds of measures, each kind having its particular unit and a certain number of multiples and sub-multiples of that unit.

The units of measure are;—

The mètre,	for the	measure of	length.	The stère,	for the	measure of	solidity.
„ are,	„	„	surface.	„ gramme,	„	„	weight.
„ litre,	„	„	capacity.	„ franc,		„	money.

Besides these, there are still the square mètre and the cubic mètre, which are used to measure surfaces and volumes in general.

In each measure the higher denominations are derived from the unit by multiplication by ten, or some power of ten; the lower denominations are obtained by dividing the unit by ten, or some power of ten. All the larger measures or multiple measures therefore contain the unit a number of times, which is represented by some power of ten; similarly, all the less or sub-multiple measures are, if the unit of measure be represented by 1, powers of $\frac{1}{10}$.

Since the number ten is the only one employed to multiply and divide the units of measure the system is called a decimal system.

The multiples are designated by the Greek words;—Déca, signifying 10; Hecto, 100; Kilo, 1000; Myria, 10,000.

The sub-multiples by the Latin words, Déci, which signifies $\frac{1}{10} = 0\cdot1$; Centi, $\frac{1}{100} = 0\cdot01$; Milli, $\frac{1}{1000} = 0\cdot001$.

These terms are prefixed to the names of the units, thus;—

The décalitre is a measure of 10 litres; the hectogramme is a weight of 100 grammes; the kilomètre is a measure of 1000 mètres; the décilitre is the tenth part of a litre; the centigramme is the hundredth part of a gramme; the millimètre is the thousandth part of a mètre.

Only the mètre and gramme have all the multiples; the other units offer a series of multiples and sub-multiples more or less incomplete, as may be seen in the following Table;—

General Table of the Metric System

	Length.	Surface.	Capacity.	Solidity.	Weight.	
	Mètre	Are	Litre	Stère	Gramme	(*Unit*) = 1·
Déca	mètre	..	litre	stère	gramme	= 10·
Hecto	mètre	are	litre	..	gramme	= 100·
Kilo	mètre	..	litre	..	gramme	= 1000·
Myria	mètre	..	..	..	gramme	= 10000·
Déci	mètre	..	litre	stère	gramme	= 0·1
Centi	mètre	are	litre	..	gramme	= 0·01
Milli	mètre	..	litre	..	gramme	= 0·001

Measures of Length.—The mètre is the base of the metric system, and the unit of the measures of length.

It is equal to the ten-millionth part of the quarter of the terrestrial meridian; that is to say, of the distance between the equator and the poles.

The earth being a sphere, all the meridians are circles, the circumference of which is divided into 360 equal parts, called degrees. The quarter of a meridian, or the distance between the poles and the equator, is therefore 90°. To ascertain this distance, it has only been necessary to determine exactly the length of one or more degrees, and this was done by measuring the part of the meridian comprised between Dunkerque and Barcelona, passing through Amiens, Paris, and Carcasonne.

The mètre is divided into ten equal parts, or décimètres; each of the latter into ten equal parts, or centimètres; and these again into ten equal parts, called millimètres.

The multiples of the mètre are;—The décamètre = 10 mètres; the hectomètre = 100 mètres; the kilomètre = 1000 mètres; the myriamètre = 10,000 mètres.

The sub-multiples are;—The décimètre = the 10th of a mètre; the centimètre = 100th of a mètre; the millimètre = 1000th of a mètre.

After having measured a length, if we find it to contain 4 décimètres and 5 centimètres, we should read it, 45 centimètres, and reduce it to the mètre thus;—$0^{m}\cdot45$, or 0·45 mètre. If we had to write 1 décimètre and 5 millimètres, we should read it 105 millimètres, and reduce it to the mètre thus; $0^{m}\cdot105$, or 0·105 mètre.

If we reduce 4 décamètres 8 mètres 5 centimètres to the mètre, we should call it 48 mètres 5 centimètres, and write it $48^{m}\cdot05$, or 48·05 mètres.

This same sum reduced to the décimètre, would be written 480·5 décimètres; the centimètre, 4805 centimètres; and the millimètre, 48,050 millimètres.

Reduced to the décamètre, would be written 4·805 décamètres; the hectomètre, 0·4805 hectomètres; and the kilomètre, 0·04805 kilomètre, or 4805 centimètres.

We may reduce in the same manner any measure by a glance at the general Table. Take, for example, 4239 kilomètres to be reduced into centimètres. We see that the kilomètre contains 100,000 centimètres, it is therefore simply necessary to add five ciphers to the 4239 kilomètres, which will be read 423,900,000 centimètres.

Thus, in order to reduce a number of one denomination to any other denomination, it is sufficient to remove the decimal point to the right or left, as many places as it is required, and give the name of the new unity, adding ciphers when it is necessary.

The facility with which these operations are performed, shows at once the advantages to be gained from uniformity in the method of forming multiples and sub-multiples of the unit. This advantage is exemplified more fully in the rules known as addition, subtraction, multiplication, and division, where the operations in each case are perfectly simple, no such difficulties as those involved in the compound rules of English money, weights, and measures being known in the metric system.

Measures of Surface.—The square mètre, which is the principal unit of superficial measure, is a square of which each side is 1 mètre in length.

The square décimètre, the square centimètre, and the square millimètre, are squares of which each side is a décimètre, a centimètre, and a millimètre in length respectively.

The square mètre contains 100 square décimètres = 10,000 square centimètres = 1,000,000 square millimètres.

The square mètre, and its sub-multiples, are employed in measuring small surfaces, as those of walls, floorings, sheets of pasteboard, glass, paper, and so on.

If we had a surface expressed in square measure, and represented by a decimal number such as 11·247805 square mètres, we should read it 11 square mètres, 24 square décimètres, 78 square centimètres, and 5 square millimètres.

If we reduce the above numbers to square décimètres, we should write 1124·7805 square décimètres, which we should read as 1124 square décimètres, 78 square centimètres, and 5 square millimètres.

The are is the unit of agrarian measures, and are used to measure the area of fields, woods, meadows, and of all landed property.

This measure is the surface of a square of which each side is 1 décamètre in length, and therefore contains 100 square mètres.

The only multiple of the are is the hectare, which contains 100 ares.

The only sub-multiple is the centiare, which is the hundredth part of an are.

The sides of the hectare, of the are, and of the centiare, decrease by ten, and their surfaces by hundred; these measures are compared thus;—The hectare to the square hectomètre containing 10,000 square mètres; the are to the square décamètre containing 100 square mètres; the centiare to the square mètre containing 1 square mètre.

The following numbers expressed in square mètres 2479654, reduced to the hectare, would be written 247·9654 hectares, and would be read 247 hectares, 96 ares, 54 centiares.

Measures of Volume.—The measures of volume are divided into three classes;—

The measure of capacity, used to determine the volume of liquids, such as wine, oil, brandy; and of dry divided matter, such as wheat, meal, or barley; and the unit of this measure is the litre.

The measure of solidity, properly so called, used to measure masonry, the volume of timber, the capacity of docks. The cubic mètre is the principal unit for this purpose.

The measure of solidity for firewood, and like material, of which the stère is the unit.

The litre, which is the unit of the measure of capacity, is equal to the cubic décimètre; that is to say, it contains as much as a hollow cube, of which the side is a décimètre. The litre is not, however, employed in the cubic form.

Of this measure there are two kinds;—The one which is used to measure liquids is made of pewter, and its height is double its diameter. The other, used to measure dry matter, is made of wood of cylindrical shape, and the height is equal to the diameter.

The multiples of the litre are;—The décalitre = 10 litres, or 10 cubic décimètres; the hectolitre = 100 litres, or 100 cubic decimètres; the kilolitre = 1000 litres, or 1000 cubic décimètres.

The sub-multiples are;—The décilitre, 10th part of the litre, 100 cubic centimètres; the centilitre, 100th part of the litre, 10 cubic centimètres; the millilitre, 1000th part of the litre, 1 cubic centimètre. The millilitre is seldom used.

The cubic mètre, the cubic décimètre, the cubic centimètre, the cubic millimètre, are cubes of which the six square faces are a mètre, décimètre, a centimètre or a millimètre square.

A cubic mètre contains 1000 cubic décimètres, 1,000,000 cubic centimètres, and 1,000,000,000 cubic millimètres. It has been shown that the square mètre is divided into 100 square décimètres.

The cubic mètre therefore contains;—$100 \times 10 = 1000$ cubic décimètres; $1000 \times 1000 = 1,000,000$ cubic centimètres; $1000 \times 1000 \times 1000 = 1,000,000,000$ cubic millimètres.

Thus in order to express in cubic mètres 36 cubic mètres 3 cubic décimètres, we write 36·003 cubic mètres. Also, to reduce to the cubic mètre, 54 cubic décimètres and 6 cubic centimètres, we must write 0·054006 cubic mètre. In the first example the 3 of the cubic décimètre is placed in the third rank of the fraction, because the cubic décimètre is the thousandth part of the cubic mètre. In the second example the 6 of the cubic centimètre is placed in the sixth rank of the fraction, because the cubic centimètre is the millionth part of a cubic mètre, and there are six ciphers in a million.

3·246 cubic mètres would be read, 3 cubic mètres 246 cubic décimètres; 0·029003005 cubic mètre would be read, 29 cubic décimètres 3 cubic centimètres and 5 cubic millimètres.

If we reduce to cubic décimètres and cubic centimètres, 3·351 cubic mètres, we should write it 3351 cubic décimètres; 3351000 cubic centimètres.

0·0005 cubic mètre would be read, 500 cubic centimètres; 0·00006 cubic mètre would be read, 60 cubic centimètres; 0·0000001 cubic mètre would be read, 100 cubic millimètres.

The stère, the unit of measure for firewood, is equal to the cubic mètre. The only multiple of the stère is the décastère, which contains 10 stères, or 10 cubic mètres. The only sub-multiple is the décistère, the tenth part of the stère = 100 cubic décimètres. The measures most in use are the half-décastère, the double-stère, and the stère. The two first are used for the sake of convenience. 3 stères 5 décistères would read 3·5 stères; 28 stères 7 décistères, 28·7 stères; 19 décastères 2 décistères, 190·2 stères. In reducing 48 stères 9 décistères to décastères, write, 4·89 décastères, and read it, 4 décastères 8 stères and 9 décistères. The same number reduced to décistères would be written, 480 décistères.

Weights.—The unit of the measures of weight is the gramme.

The gramme is the weight of a cubic centimètre of distilled water, in its state of maximum density at the temperature of 4° Centigrade, or 39¼ Fahrenheit, weighed in a vacuum.

These precautions have been taken with a view to render the gramme a constant weight.

The multiples of the gramme are;—The décagramme, or 10 grammes = the weight of 10 cubic centimètres of water; the hectogramme, or 100 grammes = the weight of 100 cubic centimètres

of water; the kilogramme, or 1000 grammes = the weight of 1000 cubic centimètres of water. A litre of distilled water weighs 1 kilogramme. The myriagramme, or 10,000 grammes = 10 kilogrammes, which is the usual term employed in designating it; the metric quintal, or metric hundred-weight = 100 kilogrammes; the millier, tonneau de mer, or ton of shipping = 1000 kilogrammes, or 1 cubic mètre of distilled water. The sub-multiples of the gramme are;—The décigramme, 10th part of a gramme; the centigramme, 100th part of a gramme; the milligramme, 1000th part of a gramme.

All these weights as actually in use are iron or copper; but in order to facilitate trade, the doubles and the halves of those weights are used, as ½ kilogramme, 2 kilogrammes, and so on.

To express in grammes;—2 décagrammes 5 grammes 5 décigrammes, write 25·5 grammes; 40 kilogrammes 25 grammes 5 décigrammes, 40025·5 grammes; 10 centigrammes 2 milligrammes, 0·102 gramme; 35 kilogrammes 3 hectogrammes 5 milligrammes, 35300·005 grammes.

3·735 kilogrammes should read 3 kilogrammes 7 hectogrammes and 35 grammes; 32 34 grammes, 32 grammes and 34 centigrammes; 0·006 gramme, 6 milligrammes.

If we reduce to décagrammes, hectogrammes, and kilogrammes, 143·2 grammes, we should write, 14·32 décagrammes; 1·432 hectogramme; 0·1432 kilogramme.

The same number of grammes reduced to décigrammes, centigrammes, and milligrammes, would be written, 1432 décigrammes; 14320 centigrammes; 143200 milligrammes.

Though we generally say 32 grammes, instead of 3 décagrammes and 2 grammes; 250 grammes, instead of 2 hectogrammes and 5 décagrammes; it is well, nevertheless, to bear in mind the primitive number, which will give a better conception of its value.

In order to find the weight of any volume of distilled water, it is only necessary to know that the litre, the unit of capacity, weighs one kilogramme, and we can at once see the connection between the measures of volume and weight, in the multiples and sub-multiples.

Thus 1 litre equals in weight 1 kilogramme; 10, 10 kilogrammes; 100, 100 kilogrammes; 1000, 1000 kilogrammes; 1 décilitre, 1 hectogramme; 1 centilitre, 1 décagramme; 1 millilitre, 1 gramme.

We can obtain as easily the weight of all bodies, whether liquid or solid, when we know their specific gravity or weight. By specific gravity, we mean the weight of any body, liquid or solid, of any given volume, as compared with the same volume of distilled water at 4° Centigrade.

For example, the specific gravity of olive oil is 0·9153, that is to say, olive oil is to distilled water, equal bulks, as 0·9153 is to 1. The specific gravity of melted copper is 8 788, that is to say, a cubic décimètre of that metal weighs 8 kilogrammes 788 grammes, since a cubic décimètre of water weighs 1 kilogramme.

Thus the weight of a body, solid or liquid, being given, in order to find its volume, divide its weight by its specific gravity; and to estimate its weight when its volume is given, multiply its volume by its specific gravity.

A similar relation to that which exists between the litre and the kilogramme, in all its multiples and sub-multiples, also exists between the cubic mètre and the kilogramme, as shown in the following Table;—

1·		Cubic	Mètre	equals	1000	Kilogrms.
0·1	or 100	„	Décimètres	„	100	„
0·01	10	„	„	„	10	„
0·001	1	„	„	„	1	„
0·0001	100	„	Centimètres	„	1	Hectogr.
0·00001	10	„	„	„	1	Décagr.
0·000001	1	„	„	„	1	Gramme.
0·0000001	100	„	Millimètres	„	1	Décigr.
0·00000001	10	„	„	„	1	Centigr.
0·000000001	1	„	„	„	1	Milligr.

The following tabulated forms give a comparison of the more common English and Metric weights and measures;—

Surveying Measure (Lineal).

ins.	links.	feet.	yards.	chains.	mile.	French mètres.
1 =	126 =	·0833 =	·0278 =	·00126 =	0000158 =	·0254
7·92 =	1 =	·66 =	·22 =	01 =	·000125 =	·2012
12 =	1·515 =	1 =	·333 =	·01515 =	·000189 =	·3048
36 =	4·545 =	3 =	1 =	·04545 =	·000568 =	·9144
792 =	100 =	66 =	22 =	1 =	·0125 =	20·116
63360 =	8000 =	5280 =	1760 =	80 =	1 =	1609·315

1 knot or geographical mile = 6082·66 ft. = 1854 mètres = 1·152 statute mile.
1 Admiralty knot = 1·1515 mile = 6080 ft.

Square Measure.

ins.	feet.	yards.	perches.	roods.	acre.	square mètres.
1 =	·00694 =	·000772 =	·0000255 =	00000064 =	·000000159 =	·000645
144 =	1 =	111 =	·00367 =	0000918 =	000023 =	·0929
1296 =	9 =	1 =	·0331 =	·000826 =	·0002062 =	·8361
39204 =	272¼ =	30¼ =	1 =	·025 =	·00625 =	25·292
1568160 =	10890 =	1210 =	40 =	1 =	·25 =	1011·7
6272640 =	43560 =	4840 =	160 =	4 =	1 =	4046·7

1 chain wide .. = 8 acres a mile.
10 square chains = 1 acre.
1 hectare .. = 2·471143 acres.
1 square mile { = 27878400 sq. feet. = 3097600 sq. yards. = 640 acres.
Acres × ·0015625 = sq. miles.
Sq. yds. × ·000000323 = sq. miles.

Cubic Measure.

ins.	feet.	yard.	cubic mètre, or stère.
1 =	·0005788 =	·000002144 =	·000016386
1728 =	1	= ·03704	= ·028315
46656 =	27	= 1	= ·764518

Measure of Capacity.

pints.	gall.	peck.	bushel.	quarter.	wey.	last.	cub. ft.	litres.
1 =	·125 =	·0625 =	·01562 =	·00195 =	·00039 =	·000195 =	·02 =	·5676
8 =	1 =	·5	= ·125	= ·0156	= ·00312 =	·00156	= ·1604 =	4·541
16 =	2 =	1	= ·25	= ·03125 =	·00625 =	·00312	= ·3208 =	9·082
64 =	8 =	4	= 1	= ·125	= ·025	= ·0125	= 1·283	= 36·32816
512 =	64 =	32	= 8	= 1	= ·2	= 1	= 10·264 =	290·625
2560 =	320 =	160	= 40	= 5	= 1	= ·5	= 51·319 =	1453·126
5120 =	640 =	320	= 80	= 10	= 2	= 1	= 102·64 =	2906·25

Long Measure.

	Mètres.	Inches.	Feet.	Yards.	Miles.
Millimètre	·001	·03937	·00328	·00109	..
Centimètre	·01	·3937	·0328	·0109	..
Décimètre	·1	3·937	·328	·1093	·00006
Mètre; 1 mètre = 1·093633056 yard ..	1	39·37079	3·2809	1·09363	·00062
Décamètre	10	..	32·809	10·936	·0062
Hectomètre	100	..	328	109·36	·06214
Kilomètre	1000	..	3280·9	1093·6	·62138
Myriamètre	10000	..	..	..	6·21382

Square Measure.

	Square mètres.	Square inches.	Square feet.	Square yards.	Acres.
Milliare	·1	155	1·076	·119	..
Centiare; or 1 sq. mètre = 1·196033292 sq. yd.	1	1550	10·764	1·19	·00025
Déciare	10	15501	107·64	11·96	·0025
Are	100	..	1076·4	119·6	·0247
Decare	1000	..	..	1196	·2474
Hectare	10000	..	..	11960	2·4711

Solid Measure.

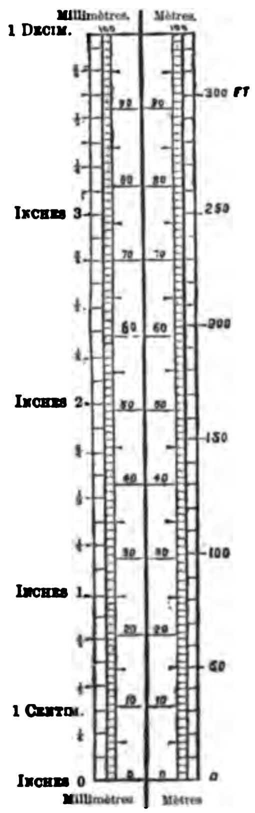
	Cubic mètres.	Cubic inches.	Cubic feet.	Cubic yards.
Millistère	·001	61·028	..	..
Centistère	·01	610·28	·353	..
Décistère..	·1	6102·8	3·5317	·1308
Stère, or cubic mètre ..	1	61028	35·317	1·308
Décastère	10	..	..	13·08
Hectostère	100	..	..	130·802

Weights.

	Grammes.	Avoirdupois oz.	Avoirdupois lbs.	Cwts.	Tons.	Grains Troy.
Milligramme ..	·001	..	..	..	..	·015
Centigramme ..	·01	..	..	..	..	·154
Décigramme ..	·1	..	..	..	..	1·543
Gramme	1	·035	·0022	..	..	15·432349
Décagramme ..	10	·35	·022	..	..	..
Hectogramme	100	3·527	·22046	..	..	..
Kilogramme ..	1,000	35·2739	2·2046	·019	·00098	..
Myriagramme	10,000	..	22·04	·1968	·00984	..
Quintal	100,000	..	220·46	1·9684	·0984	..
Millier or Bar	1,000,000	..	2204·62	19·684	·984206	..

Dry and Fluid Measure.

	Litres.	Inches.	Feet.	Gallons.	Bushels.
Millilitre	·001	·061	..	·00022	..
Centilitre	·01	·61	..	·0022	..
Décilitre	·1	6·1	..	·022	·0027
Litre; litre = ·22009668 gallon = a cubic décimètre	1	61·02	·0353	·22	·0275
Décalitre	10	610·28	·353	2·2	·276
Hectolitre	100	..	3·53	22	2·751
Kilolitre; kilolitre = a cubic mètre	1000	..	35·317	220	27·512
Myrialitre	10000	..	353·17	2200·967	27·5121



Comparative scale of English and French measures. This scale may be used for any other portion of the metrical system; for instance, if décimètres be used instead of mètres, the corresponding scale of feet will be 5—10—15 feet respectively, instead of 50—100—150; 10 décimètres being equal to the mètre.

French Mètre reduced to English Inches.

Mètre.	Inches.
·001587	= $\frac{1}{16}$
·00317	= $\frac{1}{8}$
·00476	= $\frac{3}{16}$
·00635	= $\frac{1}{4}$
·00794	= $\frac{5}{16}$
·00952	= $\frac{3}{8}$
·01111	= $\frac{7}{16}$
·01270	= $\frac{1}{2}$
·01429	= $\frac{9}{16}$
·01587	= $\frac{5}{8}$
·01746	= $\frac{11}{16}$
·01905	= $\frac{3}{4}$
·02064	= $\frac{13}{16}$
·02222	= $\frac{7}{8}$
·02381	= $\frac{15}{16}$
·02540	= 1
·05078	= 2
·0762	= 3
·1016	= 4
·1270	= 5
·1524	= 6
·1778	= 7
·2032	= 8
·2286	= 9
·2540	= 10
·2794	= 11
·3048	= 12

Milli-mètres.	Mètre.	Inches.	Feet.
1 =	·001 =	·03937 =	·00328
2 =	·002 =	·07874 =	·00656
3 =	·003 =	·11811 =	·00984
4 =	·004 =	·15748 =	·01312
5 =	·005 =	·19685 =	·01641
6 =	·006 =	·23622 =	·01969
7 =	·007 =	·2756 =	·02397
8 =	·008 =	·31497 =	·02625
9 =	·009 =	·35434 =	·02953
Centi-mètres.			
1 =	·01 =	·3937 =	·0328
2 =	·02 =	·7874 =	·0656
3 =	·03 =	1·1811 =	·0984
4 =	·04 =	1·5748 =	·1312
5 =	·05 =	1·9685 =	·1641
6 =	·06 =	2·3622 =	·1969
7 =	·07 =	2·756 =	·2397
8 =	·08 =	3·1497 =	·2625
9 =	·09 =	3·5434 =	·2953
Déci-mètres.			
1 =	·1 =	3·9371 =	·3281
2 =	·2 =	7·8742 =	·6562
3 =	·3 =	11·8112 =	·9843
4 =	·4 =	15·7483 =	1·3124
5 =	·5 =	19·6854 =	1·6404
6 =	·6 =	23·6225 =	1·9685
7 =	·7 =	27·5596 =	2·3966
8 =	·8 =	31·4966 =	2·6247
9 =	·9 =	35·4337 =	2·9528

The mètre = 3·2808992 feet.

PRESSURE.—LBS. A SQUARE INCH COMPARED WITH KILOGRAMMES A SQUARE CENTIMÈTRE.

Lbs. per inch.	Kilogs. per cent.	Lbs. per inch.	Kilogs. per cent.	Lbs. per inch.	Kilogs. per cent.	Lbs. per inch.	Kilogs. per cent.	Lbs. per inch.	Kilogs. per cent.	Lbs. per inch.	Kilogs. per cent.	Lbs. per inch.	Kilogs. per cent.
1	0·0703	16	1·125	31	2·18	45	3·16	59	4·15	73	5·13	87	6·12
2	0·1406	17	1·195	32	2·25	46	3·23	60	4·22	74	5·20	88	6·19
3	0 2109	18	1·265	33	2·32	47	3·30	61	4·29	75	5·27	89	6·26
4	0·2812	19	1·336	34	2·39	48	3·37	62	4·36	76	5·34	90	6·33
5	0·3515	20	1·406	35	2·46	49	3·44	63	4·43	77	5·41	91	6·40
6	0·4218	21	1·48	36	2·53	50	3·51	64	4·50	78	5·48	92	6·47
7	0·4921	22	1·55	37	2·60	51	3·58	65	4·57	79	5·55	93	6·54
8	0·5624	23	1·62	38	2·67	52	3·65	66	4·64	80	5 62	94	6 61
9	0·6327	24	1·69	39	2·74	53	3·72	67	4·71	81	5·69	95	6·68
10	0·7023	25	1·76	40	2·81	54	3·80	68	4·78	82	5·76	96	6·75
11	0·773	26	1·83	41	2·88	55	3·87	69	4·85	83	5·83	97	6·82
12	0·843	27	1·90	42	2 95	56	3·94	70	4·92	84	5 90	98	6 89
13	0 914	28	1·97	43	3·02	57	4·01	71	4·99	85	5 97	99	6·96
14	0·984	29	2·04	44	3·09	58	4·08	72	5·06	86	6·04	100	7·03
15	1·055	30	2·11										

COMPARATIVE TABLE OF KILOGRAMMES, LBS., AND CWTS.

Kilogs.	Lbs. Avoir.	Cwts.	Kilogs.	Lbs. Avoir.	Cwts.	Kilogs.	Lbs. Avoir.	Cwts.	Kilogs.	Lbs. Avoir.	Cwts.
1	2·20	·0197	27	59·52	·531	53	116·84	1·043	78	171·96	1·535
2	4·41	·0394	28	61·73	551	54	119·05	1·063	79	174·16	1·555
3	6 62	·0591	29	63·93	·571	55	121 25	1·083	80	176 37	1·575
4	8·82	·0787	30	66·14	·590	56	123·45	1·102	81	178·57	1·594
5	11·02	·0984	31	68·34	·610	57	125 66	1 122	82	180 78	1·614
6	13·23	·1181	32	70·55	·630	58	127·87	1 142	83	182·98	1·634
7	15·43	·1378	33	72·75	·650	59	130·07	1 161	84	185·19	1·653
8	17·64	·1575	34	74 96	669	60	132·23	1·181	85	187·39	1·673
9	19·84	·1771	35	77·16	689	61	134 48	1 201	86	189 60	1·693
10	22 05	·1968	36	79·37	·709	62	136 68	1 220	87	191·80	1·712
11	24·25	·2165	37	81 57	·728	63	138·89	1 240	88	194 01	1·732
12	26 45	·2362	38	83 78	·748	64	141·09	1·259	89	196·21	1·752
13	28 66	·2559	39	85 98	·768	65	143 30	1 279	90	198 42	1·772
14	30·86	2756	40	88·18	·787	66	145·50	1 299	91	200·62	1·791
15	33 07	2953	41	90 39	·807	67	147·71	1 319	92	202·82	1 811
16	35·27	·3150	42	92 59	827	68	149 91	1 338	93	205 03	1·831
17	37 48	3346	43	94 80	·846	69	152·12	1 358	94	207·23	1·850
18	39 68	3544	44	97·00	866	70	154 32	1 378	95	209·44	1 869
19	41·89	3740	45	99 21	·886	71	156·53	1 398	96	211·64	1 888
20	44·09	·3937	46	101 41	905	72	158·73	1 417	97	213 85	1·909
21	46 30	·4134	47	103·62	·925	73	160·94	1·437	98	216·05	1·929
22	48·50	·4331	48	105 82	·945	74	163·14	1·457	99	218 26	1 949
23	50·70	4527	49	108 03	964	75	165 35	1·476	100	220·46	1·968
24	52 91	4724	50	110 23	984	76	167·55	1·496	101	222 66	1·988
25	55·11	·4921	51	112·43	1 004	77	169 75	1·516	102	224·87	2 008
26	57 32	·512	52	114 64	1 024						

ENGLISH AND FRENCH LINEAR MEASURES COMPARED.

English. Inches. 32nds.	French. M.	C.	Mm.
1	0	0	0·79
2	0	0	1·58
3	0	0	2·38
4 or ⅛	0	0	3·17
5	0	0	3·96
6	0	0	4·75
7	0	0	5·55
8 or ¼	0	0	6·34
9	0	0	7·13
10	0	0	7·93
11	0	0	8·72
12 or ⅜	0	0	9·51
13	0	1	0·30
14	0	1	1·10
15	0	1	1·89
16 or ½	0	1	2·68
17	0	1	3·47
18	0	1	4·27
19	0	1	5·16
20 or ⅝	0	1	5·86
21	0	1	6·65
22	0	1	7·44
23	0	1	8·23
24 or ¾	0	1	9·03
25	0	1	9·82
26	0	2	0·61
27	0	2	1·41
28 or ⅞	0	2	2·20
29	0	2	2·99
30	0	2	3·79
31	0	2	4·58
32 or 1 in.	0	2	5·399

English. Inches.	French. M.	C.	Mm.
1	0	2	5·40
⅛	0	2	8·56
¼	0	3	1·73
⅜	0	3	4·90
½	0	3	8·07
⅝	0	4	1·25
¾	0	4	4·42
⅞	0	4	7·59
2	0	5	0·79
⅛	0	5	3·96
¼	0	5	7·13
⅜	0	6	0·30
½	0	6	3·47
⅝	0	6	6·65
¾	0	6	9·82
⅞	0	7	2·99
3	0	7	6·19
⅛	0	7	9·36
¼	0	8	2·53
⅜	0	8	5·70
½	0	8	8·87
3⅝	0	9	2·04
¾	0	9	5·22
⅞	0	9	8·39
4	0	10	1·60
⅛	0	10	4·77
¼	0	10	7·94
⅜	0	11	1·11
½	0	11	4·28
⅝	0	11	7·46
¾	0	12	0·63
⅞	0	12	3·80
5	0	12	6·99
⅛	0	13	0·16
¼	0	13	3·33
⅜	0	13	6·50
½	0	13	9·67
⅝	0	14	2·85
¾	0	14	6·02
⅞	0	14	9·19
6	0	15	2·39
⅛	0	15	5·56
¼	0	15	8·73
⅜	0	16	1·90
½	0	16	5·07
⅝	0	16	8·25
¾	0	17	1·42
⅞	0	17	4·59
7	0	17	7·79
⅛	0	18	0·96
¼	0	18	4·13
⅜	0	18	7·30
½	0	19	0·47
⅝	0	19	3·65
¾	0	19	6·82
⅞	0	19	9·99
8	0	20	3·19
⅛	0	20	6·36
¼	0	20	9·53
⅜	0	21	2·70
½	0	21	5·87
⅝	0	21	9·05
¾	0	22	2·22
⅞	0	22	5·39
9	0	22	8·59
⅛	0	23	1·76
¼	0	23	4·93
⅜	0	23	8·10
½	0	24	1·27
⅝	0	24	4·45
¾	0	24	7·62
⅞	0	25	0·79
10	0	25	3·99
⅛	0	25	7·16
¼	0	26	0·33
⅜	0	26	3·50
½	0	26	6·67
⅝	0	26	9·85
¾	0	27	3·02
10⅞	0	27	6·19
11	0	27	9·39
⅛	0	28	2·56
¼	0	28	5·73
⅜	0	28	8·90
½	0	29	2·07
⅝	0	29	5·25
¾	0	29	8·42
⅞	0	30	1·59
12	0	30	4·79

English. Feet.	French. M.	C.	Mm.
1	0	30	4·79
2	0	60	9·6
3	0	91	4·4
4	1	21	9·2
5	1	52	4·0
6	1	82	8·8
7	2	13	3·6
8	2	43	8·4
9	2	74	3·2
10	3	04	8·0
11	3	35	2·8
12	3	65	7·6
13	3	96	2·4
14	4	26	7·2
15	4	57	2·0
16	4	87	6·8
17	5	18	1·6
18	5	48	6·4
19	5	79	1·2
20	6	09	6·0
21	6	40	0·8
22	6	70	5·6
23	7	01	0·4
24	7	31	5·2
25	7	62	0·0
26	7	92	4·8
27	8	22	9·6
28	8	53	4·4
29	8	83	9·2
30	9	14	4·0
31	9	44	8·8
32	9	75	3·6
33	10	05	8·4
34	10	36	3·2
35	10	66	8·0
36	10	97	2·8
37	11	27	7·6
38	11	58	2·4
39	11	88	7·2
40	12	19	2·0
41	12	49	6·8
42	12	80	1·6
43	13	10	6·4
44	13	41	1·2
45	13	71	6·0
46	14	02	0·8
47	14	32	5·6
48	14	63	0·4
49	14	93	5·2
50	15	24	0·0

French and English Linear Measures Compared.

French. Mm.	English. Inches.		In. 32nds.
1	0·03937	or	0 1 F
2	0·07874	„	0 3 B
3	0·11811	„	0 4 B
4	0 15748	„	0 5 F
5	0·19685	„	0 6 F
6	0·23622	„	0 8 B
7	0·27559	„	0 9 B
8	0·31496	„	0 10 F
9	0·35433	„	0 11 F
10	0·39370	„	0 13 B

M. Cm.	Inches.		In. 32nds.
0 1	0·3937	or	0 13
0 2	0·7874	„	0 25
0 3	1·1811	„	1 6
0 4	1·5748	„	1 18
0 5	1·9685	„	1 31
0 6	2·3622	„	2 12
0 7	2·7559	„	2 24
0 8	3·1496	„	3 5
0 9	3·5433	„	3 18
0 10	3·9370	„	3 30
0 11	4·3307	„	4 11
0 12	4·7244	„	4 23
0 13	5·1181	„	5 4
0 14	5·5118	„	5 16
0 15	5·9055	„	5 29
0 16	6·2992	„	6 10
0 17	6·6929	„	6 21
0 18	7·0866	„	7 3
0 19	7·4803	„	7 16
0 20	7·8740	„	7 28
0 21	8·2677	„	8 8
0 22	8·6614	„	8 22
0 23	9·0551	„	9 2
0 24	9·4488	„	9 14
0 25	9·8425	„	9 27
0 26	10·2362	„	10 8
0 27	10·6299	„	10 20
0 28	11·0236	„	11 1
0 29	11·4173	„	11 13

French. M. Cm.	English. Inches.		In. 32nds.
0 30	11·8110	or	11 26
0 31	12·2047	„	12 11
0 32	12·5984	„	12 19
0 33	12·9921	„	12 31
0 34	13·3858	„	13 12
0 35	13·7795	„	13 25
0 36	14·1732	„	14 6
0 37	14·5669	„	14 18
0 38	14·9606	„	14 31
0 39	15·3543	„	15 11
0 40	15·7480	„	15 24
0 41	16·1417	„	16 4
0 42	16·5354	„	16 17
0 43	16·9291	„	16 30
0 44	17·3228	„	17 10
0 45	17·7165	„	17 23
0 46	18·1102	„	18 4
0 47	18·5039	„	18 16
0 48	18·8976	„	18 29
0 49	19·2913	„	19 9
0 50	19·6850	„	19 22
0 51	20·0787	„	20 3
0 52	20·4724	„	20 15
0 53	20·8661	„	20 28
0 54	21·2598	„	21 8
0 55	21·6535	„	21 21
0 56	22·0472	„	22 2
0 57	22·4409	„	22 14
0 58	22·8346	„	22 27
0 59	23·2283	„	23 5
0 60	23·6220	„	23 20
0 61	24·0157	„	24 1
0 62	24·4094	„	24 13
0 63	24·8031	„	24 26
0 64	25·1968	„	25 6
0 65	25·5905	„	25 17
0 66	25·9842	„	25 31
0 67	26·3779	„	26 12
0 68	26·7716	„	26 25
0 69	27·1653	„	27 5
0 70	27·5590	„	27 18
0 71	27·9527	„	27 31
0 72	28·3464	„	28 11

French. M. Cm.	English. Inches.		In. 32nds.
0 73	28·7401	or	28 24
0 74	29·1338	„	29 9
0 75	29·5275	„	29 16
0 76	29·9212	„	29 30
0 77	30·3149	„	30 10
0 78	30·7086	„	30 23
0 79	31·1023	„	31 3
0 80	31·4960	„	31 16
0 81	31·8897	„	31 29
0 82	32·2834	„	32 9
0 83	32·6771	„	32 21
0 84	33·0708	„	33 2
0 85	33·4645	„	33 13
0 86	33·8582	„	33 27
0 87	34·2519	„	34 8
0 88	34·6456	„	34 21
0 89	35·0393	„	35 1
0 90	35·4330	„	35 14
0 91	35·8267	„	35 27
0 92	36·2204	„	36 7
0 93	36·6141	„	36 16
0 94	37·0078	„	37 0
0 95	37·4015	„	37 13
0 96	37·7952	„	37 25
0 97	38·1889	„	38 22
0 98	38·5826	„	38 17
0 99	38·9763	„	38 31
1 00	39·3700	„	39 12

M. Cm.	Ft.	Inches.		Ft. In. 32nds.
1 00	3	3·370	or	3 3 12
2 00	6	6·740	„	6 6 24
3 00	9	10·110	„	9 10 4
4 00	13	1·480	„	13 1 15
5 00	16	4·850	„	16 4 14
6 00	19	8·220	„	19 8 7
7 00	22	11·590	„	22 11 19
8 00	26	2·960	„	26 2 31
9 00	29	6·330	„	29 6 11
10 00	32	9·700	„	32 9 23

The letters F and B indicate that the equivalent 32nd is either Full or Bare.

MILL. Fr., *Moulin*; Ger., *Mühle*; Ital., *Mulino*; Span., *Molino*.

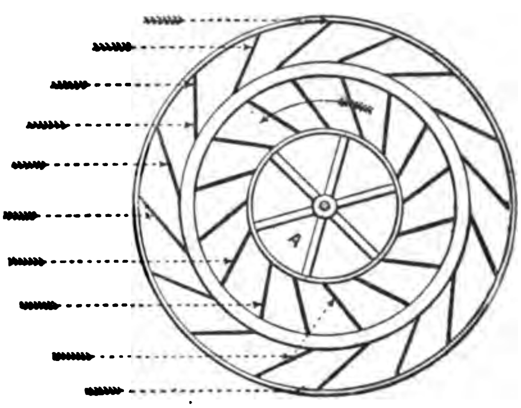
A mill is an engine or machine for grinding or comminuting any substance, as grain, by rubbing or crushing it between two hard indented surfaces, generally of stone or metal, usually having a word prefixed denoting the particular object to which it is applied; as, a rolling mill, a paint-mill, a cider-mill, and so on. In modern usage the term mill includes various other machines or combinations of machinery which resemble the flour-mill, to which the term was first applied, not in its circular crushing or grinding action, but in the more general one of transforming some raw material by mechanical processes into a state or condition for use; as saw-mills, cotton-mills, powder-mills, oil-mills, silk-mills, to some of which the term manufactory or factory is also applied. The building, with its machinery, where grinding or some process of manufacturing is carried on is also called a mill.

Windmills.—For giving motion to machinery, windmills have been and still are very extensively used. Engineers of the last generation devoted great attention to the construction of windmills, and brought them to great perfection. The introduction of steam-power—a power economical, manageable, and always to be depended on—has, in a great measure, superseded that of wind as a mover of machinery. It is true after the first cost of a windmill, the power is comparatively inexpensive; but it is so variable in intensity—sometimes, when it is not required, exerting great force, and sometimes, when it may be most wanted, totally ineffective—that it is generally preferable to apply a force, perhaps considerably more expensive in its production, but constant, steady, and completely under control.

Windmills are of two kinds, horizontal and vertical. The former have been very little used, for it is found in practice that they are by no means so effective as the latter. The mode of con-

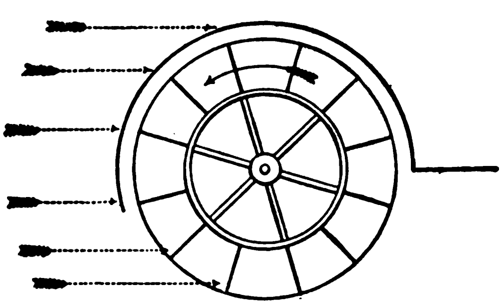
structing a horizontal windmill is like that represented on the plan, Fig. 5878, or some modification of the same principle of construction. A wheel mounted on a vertical axis or shaft, and having flat vanes or boards fitted round its circumference, is enclosed in a circular casing, which is fitted with boards fixed obliquely, or in such lines as if produced inwards would touch the circumference of the wind-wheel. By this arrangement the wind, from whatever point it may blow, causes the wheel to revolve in the same direction. Part of the breeze passes between the oblique boards of the casing, and acts on the blades of the wheel; while part is intercepted by the boards, and either reflected inwards so as to propel the blades in the same direction, or reflected outwards so as not to act upon them in the opposite direction.

5878.



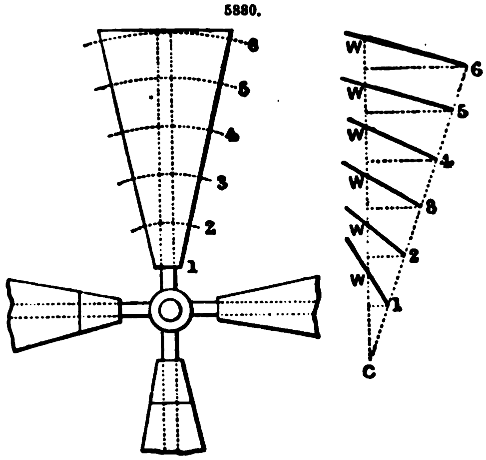
Sometimes horizontal windmills have been made with a casing partially surrounding the wind-wheel, Fig. 5879, and capable of being turned round by means of a vane, so as to permit the wind only to act on one side of the wheel, while the other is completely sheltered.

5879.



The vertical windmill, as is well known, consists of an axle or shaft, nearly horizontal, mounted in bearings at the summit of a tower, with four or more blades or sails attached to it. These sails are set at an angle with the axis, so that when the wind blows directly on the face of the mill, its oblique action on the sails is resolved into two forces—one in the direction of the axis, and the other perpendicular to it, which is the direction in which the sails revolve. Numerous experiments and computations were made to determine the most advantageous angles for setting the sails, and their most effective forms and proportions. If we suppose the radius of a sail divided into six equal parts, Fig. 5880, and circles traced through the points of division, the velocity of each point in revolving is proportional to the part of its circle intercepted between two radii, or proportional to its own radius. If, then, we make a series of plans of the sail at these different parts, we see that as we approach the centre we should increase the obliquity of the sail to its plane of motion, so as to allow for its slower escape sideways from the impulse of the wind. The sails accordingly are not made flat surfaces inclined equally to the plane of their revolution, but surfaces of varying inclination, somewhat like portions of screw blades, twisting as it were from a certain obliquity at their extremes in a greater obliquity at the centre. The angles found most advantageous in practice are given by the celebrated engineer Smeaton as follow, as well as those used by some other engineers;—

5880.



Distance from centre	1	2	3	4	5	6
Inclination to plane of motion (Smeaton)	18°	19°	18°	16°	12½°	7°
,, ,, otherwise	24°	21°	18°	14°	9°	3°

In the angles given by Smeaton an irregularity is observed in the first, which should by theoretical reasoning be greater than the second, whereas Smeaton makes it less. The following rule may be adopted as a very near approximation. To find the angle at which the sail should be inclined to the plane of revolution at any distance from the centre;—

Rule.—Multiply 18 twice by the distance from the centre, divide the product twice by the total radius, and subtract the quotient from 23; the remainder is the inclination in degrees.

Example.—In a windmill 60 ft. in diameter, required the inclination of the sail 20 ft. from the centre.

Here 30 ft. is the total radius, and $\frac{18 \times 20 \times 20}{30 \times 30} = 8$, which, subtracted from 23, gives 15°, the angle of that point.

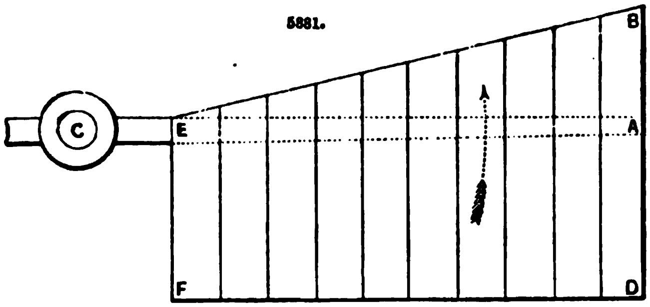
Were we to divide the radius 30 ft. into six equal parts, and calculate the angles at each point, we should find them correspond nearly with the means of those given by Smeaton and others, as may be seen by the following Table;—

Parts of radius..	1	2	3	4	5	6
Distances from centre	5 feet	10 feet	15 feet	20 feet	25 feet	30 feet
Angles (Smeaton)	18°	19°	18°	16°	12½°	7°
„ (others)	24°	21°	18°	14°	9°	8°
Means	21°	20°	18°	15°	10¾°	5°
Angles by the rule	22½°	21°	18½°	15°	10½°	5°
Differences from means	1½°	1°	½°	0°	¼°	0°

Having determined the proper inclination of the sails at different distances from the centre, it next becomes important to inquire how much of the surface of the whole circle should be filled with sails. Mills are generally made with four strong wooden arms or radii, fixed firmly in a central socket, and steadied and stiffened by tie-rods, connecting their extremities together, and with a projecting strut on the central boss. The width of each sail at the extreme should be about half of the radius, so that in a mill 60 ft. diameter, or 30 ft. radius, each sail would be 15 ft. wide at the extreme. The part of the arm next the centre for about ⅙ of the radius, that is, 5 ft. in the case supposed, is not fitted with sails because the surface there is so little effective, as well from its short leverage as from its obstructing the wind reflected from the head of the turret behind it. The width at the inner end should be ⅓ of the radius, or 10 ft. The surface of each sail is therefore 312½ sq. ft., and the total of the four is 312½ × 4 = 1250 sq. ft.

The total area of a circle 60 ft. in diameter is somewhat above 2800 sq. ft., so that not half the surface of the circle is clothed with sails. There would be no disadvantage in extending the surface by making the sails broader or more numerous, until it became ¾ of the whole surface. Beyond this additional sail-surface is disadvantageous, for it appears to obstruct the free passage of the currents reflected from the sails, and thus clog their motions. It is found advantageous to arrange the surface of a sail somewhat in the proportions of the diagram, Fig. 5881, which represents the front view of one sail.

5881.

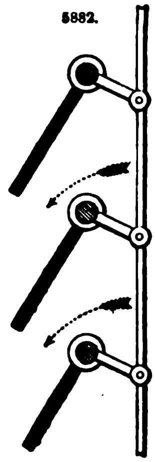


Thus if A C is 30 ft., then A E should be 25 ft., A D or E F 10 ft., and A B 5 ft.

The covering of the surface, so as to catch the impulse of wind, formerly consisted of canvas fixed on a roller at one side of the arm, on which it could be rolled like a window-blind, or from which it could be unrolled so as to cover the whole sail, which was filled in with wooden framing to support the canvas pressed against it by the wind. Sometimes the canvas, instead of being in one sheet, was subdivided into numerous separate sheets mounted on rollers, and apparatus was provided so that the canvas might be wound on the rollers or unwound at pleasure while the mill was in motion. As the wind is exceedingly variable, and as the quantity of work required of the mill also might vary to a considerable extent, it was found necessary to provide some apparatus by which the mill might regulate itself, so that its velocity should not be excessive at one time, and too small at another. One mode of effecting this object was to apply to the machinery of a mill a governor, like that of a steam-engine. This governor consists of two heavy balls suspended from the summit of a vertical revolving spindle by jointed rods. The spindle being at rest, the balls hang close to it on each side; but on the spindle being caused to revolve rapidly, the balls, im-

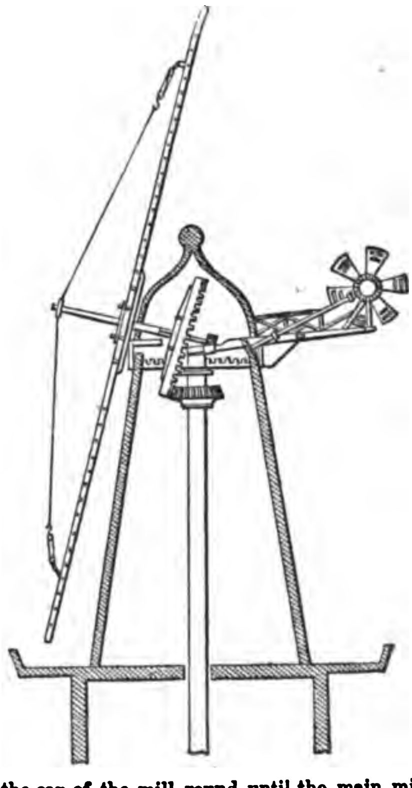
pelled by centrifugal force, fly away from the central axis. A system of levers and rods connected this apparatus with the sail-rollers, so that when the balls flew outwards from increased velocity, the sails were furled; and when they fell inwards from diminished speed of revolution, the sails were unfurled. The quantity of surface thus presented to the wind was adjusted to its force, and a tolerably equable velocity of the machinery was attained. In some more recent mills an ingenious contrivance for regulating the surface of sail according to the force of the wind has been successfully adopted. The sails consist of a framework filled in with louvre-boards hinged on pivot-pins near one of their edges, and all connected by levers and rods with a sliding boss on the central axis of the windmill, Fig. 5882. When the wind blows strongly against the louvre-boards, it forces them out of their vertical position, and passes freely through the openings between them. The surface of the sails is thus diminished by the pressure of the wind itself. To prevent its being too much diminished, the sliding boss connected with the louvre-boards is pressed upon by a lever loaded by a certain weight sufficient to balance, as far as may be desirable, the pressure tending to force aside the louvres, and thus to keep them, to a certain extent, up to their work. When the load on the mill—that is to say, the quantity of work effected by it—is varied, the weight may be varied accordingly; and thus the effective amount of surface in the sails may be adjusted to the average force of the wind and the work to be done by it. When the wind-force exceeds or falls short of its average, the greater or less inclination of the louvres very nearly compensates for the variation.

5882.



The sails of a windmill should directly face the wind in order to receive its most advantageous action; but, as the direction of the wind often changes, it is necessary to adopt some arrangement for varying that of the mill-shaft accordingly. The summit of the mill-tower, in which the mill-shaft is mounted, is therefore made to revolve, so that at any time the direction of the shaft may be varied, and the sails presented to the wind. In old mills, and indeed in many small mills still existing, this change of direction is effected by hand. A long lever is fixed to the movable cap or summit of the tower, and extends obliquely to the ground. The miller watches the direction of the wind, and by moving this lever turns the cap round to its proper position. But in large mills this would require considerable power; and, moreover, constant attention would have to be paid to the changes of the wind. Were a single change neglected the mill might be destroyed; for as the sails are made and strengthened by tie-rods to receive the wind's pressure on their face, a change of the wind to the opposite direction might throw a great strain on their back, for meeting which no provision is made. A simple mode of making the change of direction self-acting is to fit the back of the cap with a large vane, which, like that of a weathercock, would cause the sails to be presented to the wind from whatever quarter it might blow. But when mills are of considerable size the vane would require to be very large and cumbrous. The contrivance generally employed is neat and ingenious. Behind the cap, Fig. 5883, on the side opposite that through which the wind-shaft passes, a framing is made to project outwards. On this framing there is mounted a small windmill on an axis transverse to that of the main arms. The cap rests on rollers fitted in the circular top of the tower so that it may move freely round; and a toothed circular rack is also fixed on the summit of the tower. A spindle, fitted with bevel-gearing so that it may be caused to revolve by the revolution of the small mill, conveys motion to a toothed pinion which gears into the circular rack. When the main mill has its face presented to the wind, the small one stands edgeways to it, and therefore remains at rest; but as soon as the wind veers it begins to act on one side or the other of the small mill, and thus causes it to revolve. The pinion is thus made to travel along the fixed rack and turn the cap of the mill round until the main mill is again brought to face the wind in its new direction. This arrangement is found to be very effective, and when it is properly applied the mill requires no attention in respect of direction to the wind.

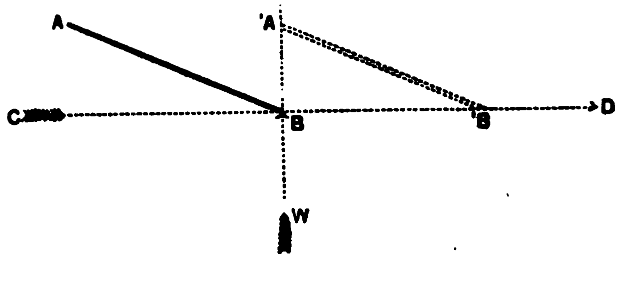
5883.



In estimating the velocity with which the sails of a windmill revolve, we have to consider not only the force of the wind upon them, but also the resistance to their motion occasioned by the work done by the mill. A, B, Fig. 5884, may represent the edge of a surface presented obliquely to the

wind, and capable of moving in the direction C, D, at right angles to that of the wind. If the surface be free and unresisted in its motion, and the wind be considered to produce its full effect upon it, the proportion of its velocity to that of the wind would be estimated by that of the line B, B', to the line B, A'; for it is clear that while the wind travels over the distance B, A, the surface moves to the position dotted, that is, over B, B'. But if the motion of the surface be resisted, its velocity in relation to that of the wind is diminished. In the case of windmill sails, we may suppose such a load of work on the mill that the velocity of the sails is not more than half what it would be were there no resistance. We may therefore assume that the velocity of the sail relatively to the wind would be expressed by the ratio of half the length of the line B, B', to the length of A, B'. Taking the wind as a gentle breeze, the velocity of which in the Table is about five miles an hour, and the inclination of the sail or angle A, B, B', half-way from the centre 18°, we should find the half of B, B', to be about $1\frac{1}{2}$ times A, B, or the velocity of the sail, $1\frac{1}{2} \times 5 = 7\frac{1}{2}$ miles an hour—about 660 ft. a minute. If the windmill be about 60 ft in diameter, the diameter of the middle point of the arm is 30 ft., the circumference of the circle in which that point revolves is 94 ft., and the number of revolutions made a minute is therefore $\frac{660}{94}$, about 7.

5884.



If now we calculate the speed of the extremities of the arms, we find that it is 1320 ft. a minute, or about 15 miles an hour; three times that of the wind, which we have assumed as 5 miles an hour. Did we assume a wind of greater velocity, we should have to take into account the self-regulating arrangement, which diminishes the amount of surface exposed, and therefore prevents the mill from attaining so much increase of speed as it would without regulation. Under ordinary circumstances the speed of the outer extremities of the arms ranges from 20 to 30 miles an hour. We may assume 30 miles an hour when the wind blows at 10 miles with a pressure of about $\frac{1}{2}$ lb. on the square foot. The total surface of the sails unfurled in a mill 60 ft. diameter, is 1250 sq. ft.; we may suppose half lost by furling, leaving 625 effective. As the surface is set obliquely to the wind, the pressure in the direction of motion would be reduced from $\frac{1}{2}$ lb. to about $\frac{1}{7}$ lb. as a mean over the whole of the arms, giving a total pressure in the direction of motion of about 90 lbs. The mean velocity of the arms is half that of the extreme, 15 miles an hour, or 1320 ft. a minute. We have therefore 90 lbs. moving at 1320 ft. a minute, which is equivalent to a force of $90 \times 1330 = 118{,}800$ lbs. moving at 1 ft. a minute. A horse-power is reckoned as equivalent to 33,000 lbs. moved 1 ft. a minute; therefore, the power of the mill we have reckoned is about $3\frac{1}{2}$ horse-power.

When we double the diameter of a mill, we quadruple its power, for we quadruple its effective surface. The areas of circles are proportional to the squares of their diameters; and as the similar parts of the areas are occupied by sails, they are also as the squares of the diameters.

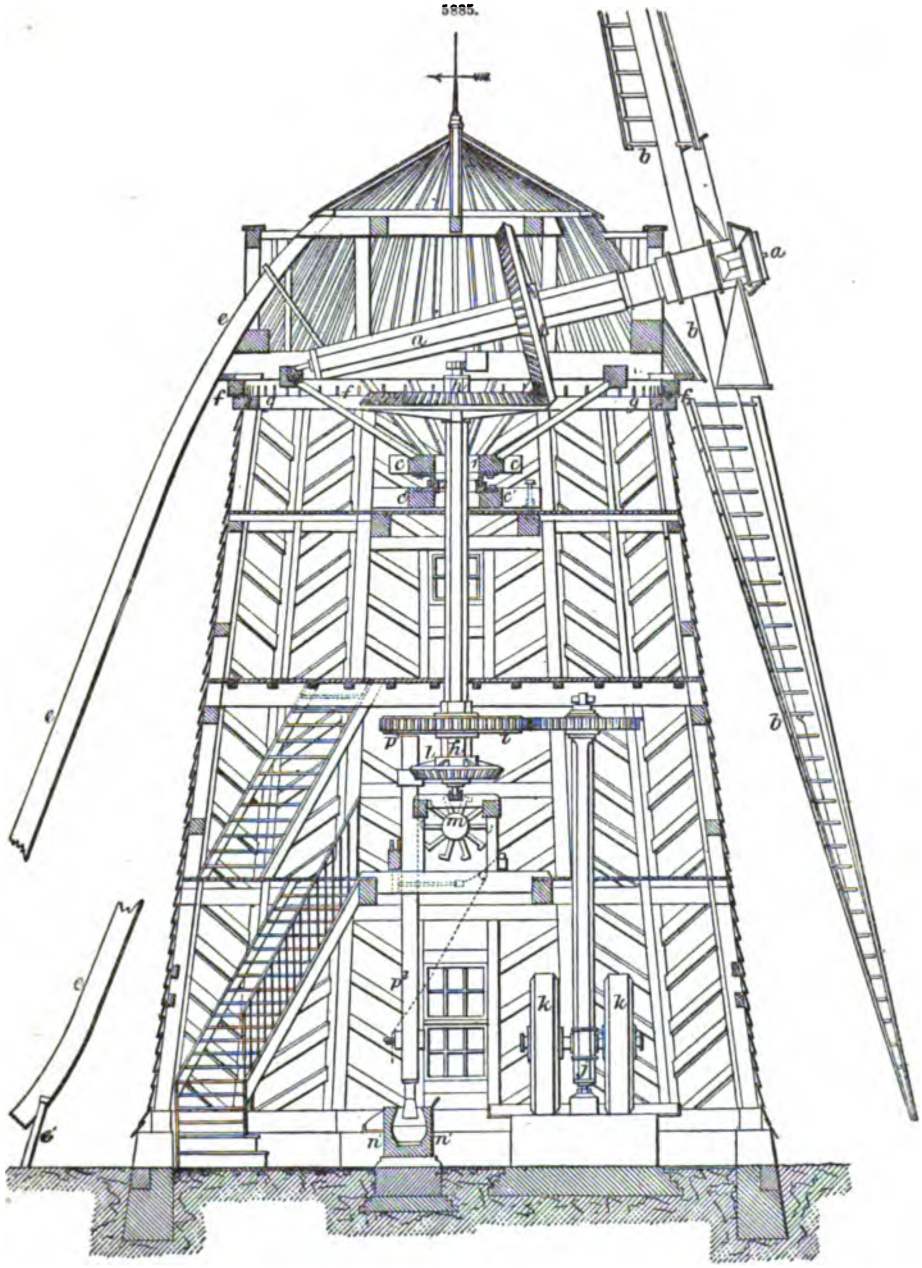
It is not at all an easy matter to estimate the powers of windmills. The proper guide as to power, velocity, and construction is experience. Some of the works of Smeaton contain much valuable information respecting this branch of practical mechanics; and to these we must refer such of our readers as require a more full discussion of the subject than our limits permit us to offer.

Fig. 5885 is a vertical section of a windmill arranged to drive the gears of a rape-oil mill. *a a* is the mill-shaft; *b*, *b*, the sails; *c c*, movable support for the mill-shaft; *e e*, hand-lever for shifting the movable mill-cap; *f*, *f*, bearings of the cap, *g g*, summit of mill-tower; *h h*, main shaft; *i*, toothed wheel and pinion turning the shaft *j* of the stones *k*, *k*; *l*, bevel-gears for driving such other machines as the stamp battery, or press, seen at p^2, n'.

As a force applied to the movement of machinery, wind has few advantages except its little cost after the first outlay for a windmill has been made. It is chiefly available in flat countries, where there is no opportunity of obtaining the preferable power of water, and where there is little interruption to the aërial currents. In hilly countries windmills are often subject to derangement from the excessive force of the gusts of wind that often occur in such regions. In tropical countries, particularly islands and places near the sea-shore, the daily occurrence of the land and sea breezes, occasioned by the action of the solar heat on the land, provides a certain amount of wind-power, which may be almost always depended on. But in these countries, on the other hand, there often occur tornadoes or hurricanes of extreme violence, that sweep away almost everything that may oppose their progress; and thus frequently destroy windmills, and occasion renewed outlay in their reconstruction. The principal use to which windmills are devoted in temperate climates is for grinding corn; in tropical climates, such as the West Indian Islands, they are employed for driving sugar-cane mills. In fenny and marshy countries, such as Holland or some of the eastern counties of England, they are used for drainage, either by working pumps or turning a wheel contrived for lifting the drainage water from the surface of the ground into canals at a higher level, by which it is carried off into the sea. In all situations, however, where the cost of fuel is not extravagantly great, steam-power has superseded that of wind, because its certainty of action more than repays the cost of its production. Districts the drainage of which is dependent on wind-power, may

frequently remain many weeks under water from the prevalence of calm weather, and the agricultural operations of the season may be so seriously interfered with that whole crops are lost, or

5885.



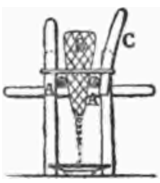
become immensely deteriorated. In sugar-growing countries again, the derangement of wind machinery by a hurricane or tempest may occur at the season when the sugar-canes have to be crushed; and the loss of a few days in crushing the canes may seriously damage the sugar in respect of quantity as well as quality. Upon the whole, then, whenever the cost of fuel is not excessive, it is not advisable to incur the outlay of extensive works for securing wind-power. A very small steam-engine, kept constantly in operation, is far more effective than a windmill of much greater power, because the latter is so variable and uncertain in its action. The only operations suited to wind-power are such as need not necessarily be completed at certain periods, but may be conducted occasionally as the wind may serve. Nor should the machinery driven by wind

require very nice regularity in its action; for, notwithstanding all the ingenious arrangements for equalizing the wind-force, it is still unsteady at the best.

Every part exposed to the wind should be greatly in excess of the strength required to resist the average strain to which it may be exposed. The tempest of an hour—nay, a momentary gust —may frequently destroy a windmill that has stood under ordinary winds for years; as a safeguard against too much strain, the windmill should always be left free to revolve, even if the machinery which it drives is thrown out of gear. The shaft or axis of the mill generally carries a large wheel, to which is fitted a strap of iron, loaded so as to press on its circumference, and act as a friction-brake either to hold the mill fast for purposes of repair during light winds, or to check its velocity when the winds are too strong for the work required.

Oil-mill Machinery, by Alex. Samuelson. Excerpt Proceedings Inst. M. E., 1858.—The means adopted for extracting oil in the last century by the natives of Ceylon, where cocoa-nuts and other seeds abound, were of the most primitive description; the apparatus, as illustrated in Fig. 5886, consisting simply of a few poles stuck into the ground, supporting two parallel horizontal bars A, A, between which was placed a bag B containing the seed or pulp of the cocoa-nut, from which the oil was to be expressed; a lever C was then brought to bear against one or both of the horizontal bars for the purpose of bringing them together, and thereby causing the required pressure upon the seed. This rude apparatus was one of the most approved oil-mills of that period. The pestle and mortar, Fig. 5887, was also used for the same purpose; and from the nature of these appliances the process was necessarily exceedingly slow and inefficient. Fig. 5888 is an improvement upon this apparatus. It is the invention of Hebert, whose object was to

5886.



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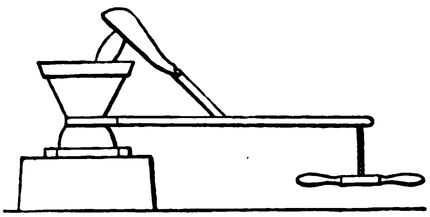

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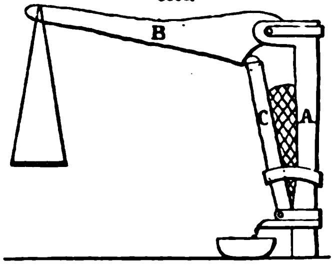

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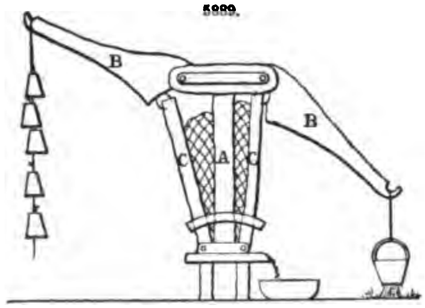

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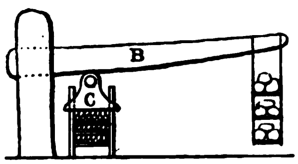
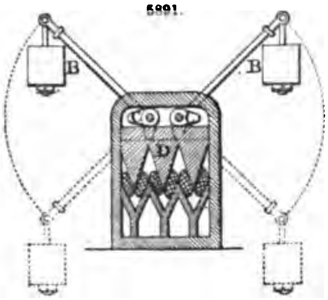


construct what he considered a powerful and effective machine, combining simplicity and cheapness with economy of labour. It consisted of an upright post A fixed firmly into the ground, the stump of a tree being often used, upon the lower and upper ends of which were projecting pieces, the upper one forming the joint of the long horizontal lever B, and the lower one the joint of the short vertical lever C, at the top of which was fixed a roller bearing against the under side of the horizontal lever B, for the purpose of diminishing the friction when the pressure was exerted upon the seed. The fixed upright post A and the vertical lever C in this instance formed the compressing portion of the machine. The pressure was obtained by the weight of a man suspended from the end of the horizontal lever B. A double machine, Fig. 5889, was also constructed upon the same principle, the pressure being obtained either by weights or by a bucket full of water, which was made self-acting in so far that as soon as the bucket touched the ground a valve was opened and the water escaped, relieving the seed from any further pressure. The advantage of the double machine was that it could be made portable and be moved about at pleasure, one-half of the press counterbalancing the other when both sides were in action, thus it was rendered independent of the ground. Another appliance of a similar description is shown in Fig. 5890; in this instance there was only one lever B, and the seed bags, instead of being placed vertically, were placed horizontally in a box C, upon the loose head of which the action of the lever was brought to bear by the same means of animate or inanimate weights. There is also another press deserving of notice, which is shown in Fig. 5891. The pressure is here gained by levers and weights B as in most of the foregoing examples, but with this modification, that cams C and wedges D are introduced. There is also a modification of this combined lever and cam machine, Fig. 5892, a press invented by John Hall, of Dartford, where the pressure is applied at the

end of the levers B by means of the steam-cylinder A. This apparatus is double, consisting of two pairs of boxes, the cams being placed opposite to each other, so that the operations of compressing the seed and refilling the bags may be carried on simultaneously.

5891.



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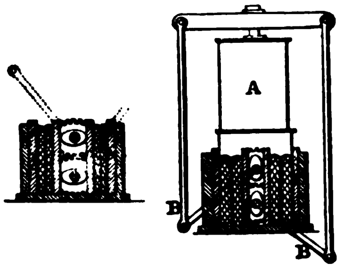
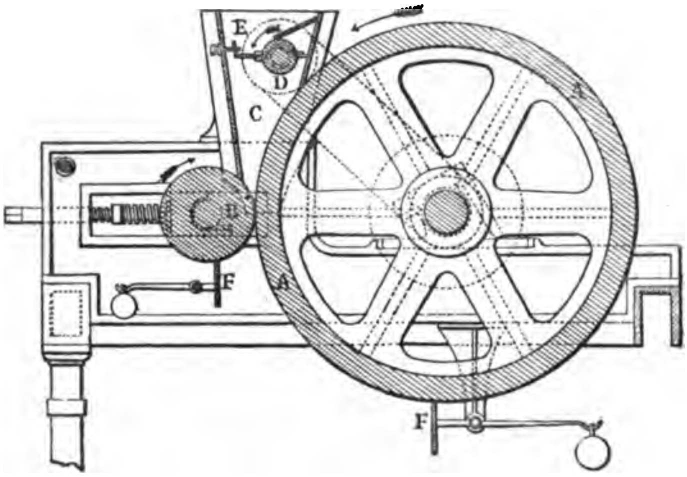


The more approved and modern presses for extracting oil are three in number;—the Dutch or stamper press; the screw press; and the hydraulic press. Before considering the comparative merits of these three presses, it will be advantageous to refer generally to the course of operations to be performed previous to the compression of the seed, which is the last of five operations that it has to undergo.

The first operation consists in passing the seed through a flat screen or shaker, which is kept in a constant state of agitation.

In the second operation the seed is passed through a pair of crushing rollers, which have the effect of bruising or crushing it. Fig. 5893 is a transverse section, and Fig. 5894 a plan, of a pair of these

5893.



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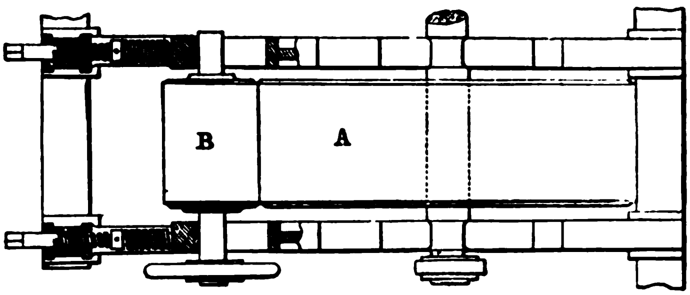

rollers. The two rollers are of unequal diameters, the larger one A being 4 ft. diameter, and the smaller B 1 ft. diameter, the breadth of both being 16 in., or 14½ in. on the face. The larger roller A makes fifty-six revolutions a minute, driving the smaller one by friction. The seed is supplied through the hopper C by means of a small roller D very slightly grooved, which is made to

revolve for the purpose of feeding the main rollers, being driven by a strap from the larger roller passing over a pulley outside the hopper; the amount of feed is regulated by the regulating plate and screw E. Underneath the rollers are placed scrapers F, kept in contact with them by weights, for the purpose of scraping off any seed adhering to the surfaces after crushing. These rollers for a long time were made of equal diameters; but it was found that they crushed the seed neither so well nor so expeditiously as they do in their present proportions. After the equal-sized rollers were found to be inefficient, that known as the Ipswich Mill was adopted, in which the larger roller was 6 ft. diameter and the smaller 1 ft. diameter; but experience proved that, when any hard substance got between the rollers, the leverage over the journals was so great that it caused much wear and tear upon those parts. Seed crushers have therefore by degrees adopted the medium-sized rollers, which are found to be exceedingly effective and not liable to derangement. A pair of rollers such as are shown in Figs. 5893, 5894, will crush, upon an average, about 4½ tons of seed in eleven hours, which is sufficient for two sets of hydraulic presses.

The third operation consists in grinding the seed under a pair of edge stones, Figs. 5895, 5896. Fig. 5895 is a vertical section, one of the stones being removed; and Fig. 5896 is a plan with one of the stones in section. Fig. 5897 shows the vertical driving shaft partly in section. The two edge stones A A are 7 ft. 6 in. diameter and 16 in. thick, bevelled to 11½ in. broad on the face, weighing together about 7 tons; the vertical driving shaft B makes about seventeen revolutions a minute. The seed is kept under the stones by means of the sweeper D, and at the proper period is collected and swept off by a second sweeper E, the slide

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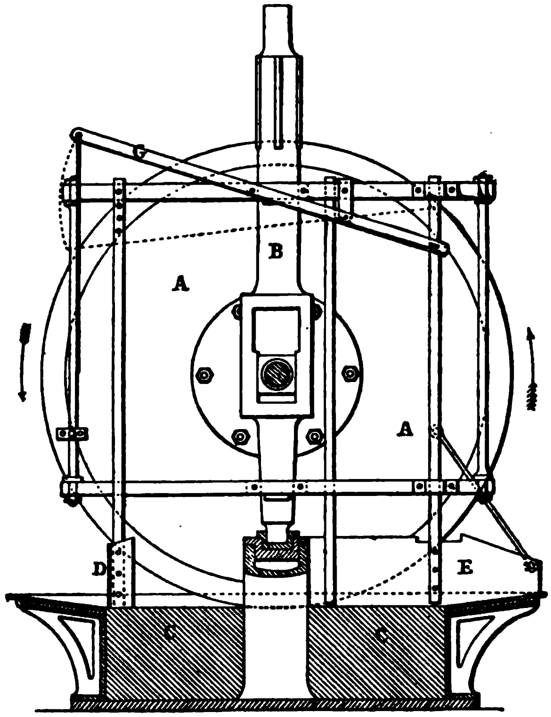

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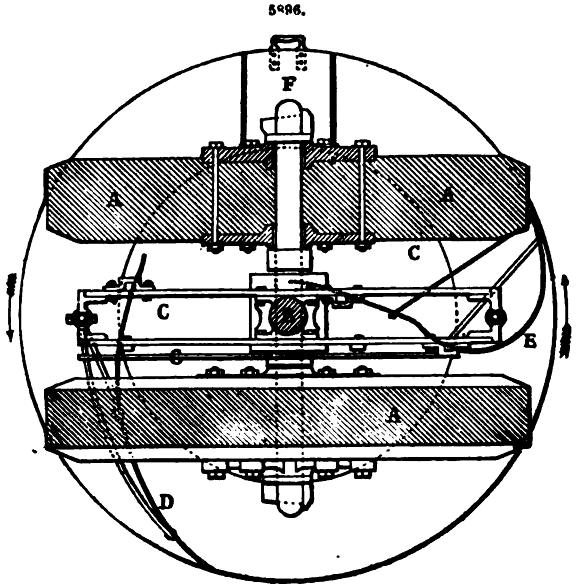

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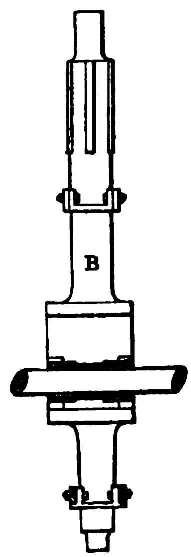
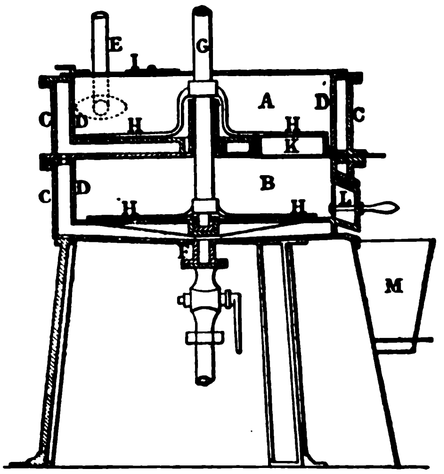


or cover F being withdrawn for its discharge; while the grinding is being performed, the sweeper E is raised from the bed-plate C, by the hand-lever G, as shown by the dotted line. The edge

stones, if of good quality and the seed not impure, require to be refaced about every three years, and will last from fifteen to twenty years according to their quality. One pair of edge stones will grind sufficient seed for two double hydraulic presses; the process of grinding lasts for about twenty-five minutes, previous to the seed being transferred to the next operation.

The fourth operation consists in heating the ground seed in the heating kettle, Figs. 5898, 5899. Fig. 5898 is a vertical section of the heating kettle, and Fig. 5899 a plan. The kettle is heated

5898.



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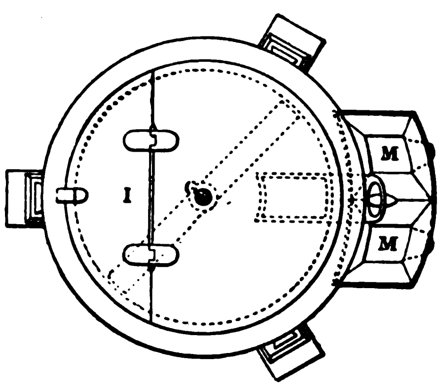
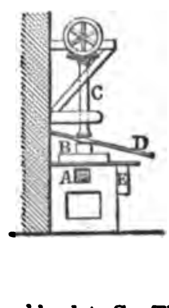


by steam, and consists of two cylindrical chambers A and B, one above the other, each of which is composed of an external casing C and an internal casing or inside kettle D, with a sufficient space left between the two casings round the sides and at the bottom to allow free circulation of the steam. The steam is admitted by the pipe E, and the condensed water passes off at F from the bottom of the kettle. The shaft G gives motion to two arms of stirrers H, H, in each chamber, revolving at the rate of thirty-six revolutions a minute, which keep the seed constantly agitated so that every particle of it may come in contact with the heated sides and bottom of the kettle. The upper chamber A is covered with a sheet-iron lid I, through which the kettle is charged. In heating the seed the upper chamber A is filled first, and the seed is allowed to remain in it from ten to fifteen minutes; the slide J is then withdrawn, and the seed falls through the opening K into the lower chamber B, where it remains until it is required to be taken to the press; the door L is then opened, and the whole of the seed is discharged from the chamber B by the action of the revolving stirrers H. The seed falls through a funnel M, under which is placed a bag of suitable dimensions to contain a sufficient quantity of seed to make a cake weighing 8 lbs. after the oil is expressed from it. Each of the chambers in the heating kettle will contain sufficient seed for charging one single press; the heating of the seed is therefore a continuous operation of first charging the upper chamber A, and then allowing the seed to pass into the lower one B, in which it is heated to 170° Fahr., and is then withdrawn and placed in the bags.

Fig. 5900 is another description of kettle, of a much simpler though less effective kind. In this case the seed is heated on a hot hearth A, being confined within a loose ring B; a spindle C with two arms upon it revolves inside the ring, keeping the seed stirred while it is being heated. When the seed has become sufficiently heated, the spindle and stirrers are raised a sufficient height above the top of the ring by the handle D; and the ring being loose on the hearth, the seed is drawn forward by it and scraped into the bag E. In this instance the seed is exposed to the atmosphere, and there is therefore a large amount of heat wasted. It is also liable to become overheated and spoiled, and upon the whole this is a more troublesome operation, as each ring holds only sufficient seed for one bag.

5900.



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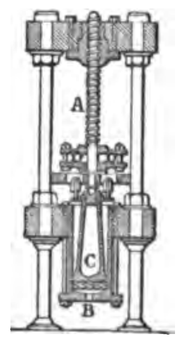


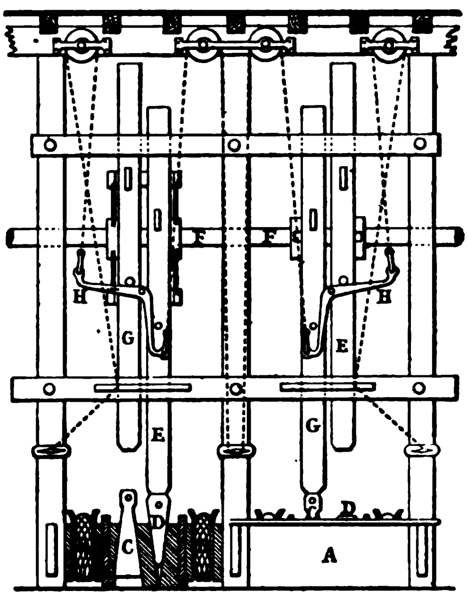
The bags after being filled are placed separately between what are called the hairs, which are bags made of horsehair with an external covering of leather. The same description of bags and hairs are used, whether the oil is expressed by means of the stamper, screw, or hydraulic press.

The final operation of expressing the oil is effected in the screw press, Fig. 5901, by means of an ordinary square-threaded screw A, by which the bag of seed is compressed between the bottom of the box B and the movable plate C. The power is applied by means of a loose lever inserted between studs fixed in the plates D, which are attached to the screw.

The press may be made in a vertical form, and may also be made to lie horizontally, and to be worked either by hand or by power. A very large amount of pressure may be obtained by one of these presses, but the wear and tear and derangement are excessive.

The stamper press, Fig. 5902, consists of a long rectangular cast-iron box A, open at the top, at each end of which there are two plates, between which one bag of seed B is placed, yielding a cake weighing 9 lbs.; next to one of the inner plates is placed a filling-up piece, then an inverted wedge C, then another filling-up piece, after which is introduced the vertical driving wedge D, and lastly another filling-up piece is inserted between the driving wedge and the other inner plate. As soon as the bags B have been placed vertically in the press-box in the usual manner, a stamper E made of wood, about 16 ft. long and 8 in. square with a fall of about 22 in. in the final stroke, is allowed to fall at the rate of fifteen strokes a minute, for a period of about six minutes, upon the head of the driving wedge D, which is sufficient to drive it down level with the top of the press-box A, the stamper being worked by two cams or wipers on the revolving shaft F. Side by side with the stamper E is a second stamper G, immediately above the inverted wedge C, which is held suspended at a fixed point by means of the lever H while the first stamper E is in action; but as soon as it is time to remove the bags, the stamper E is raised by means of the lever H above the point at which the cams come into contact with it, and by the same means the other stamper G which was previously suspended is allowed to fall upon the inverted wedge C, driving it downwards and thereby releasing the working wedge D, so that the attendant may remove the bags and repeat the operation. A press like this will not do more than about 12 cwt. of cake a day.

5902.

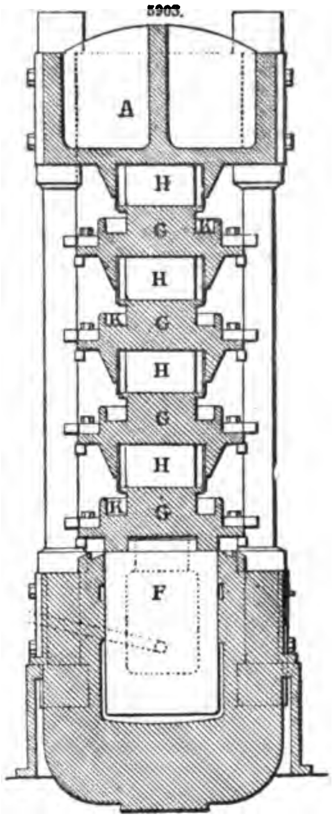


The last mode of expressing the oil is by means of the hydraulic press, which may fairly be said to be the most approved system that has yet been adopted. This press is simply Bramah's press arranged specially for the purpose of expressing oil.

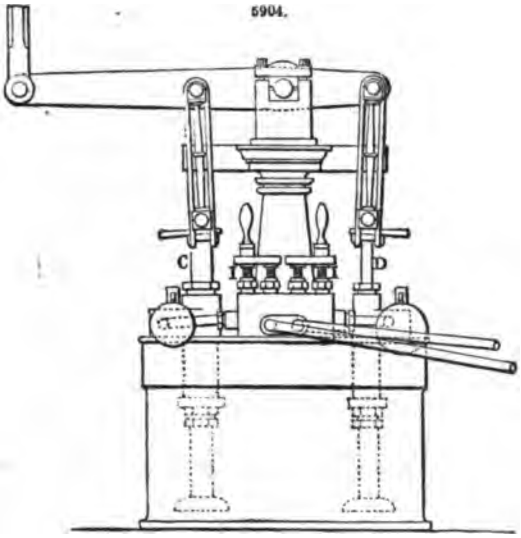
Blundell's double hydraulic press is shown in Fig. 5903, and in detail in Figs. 5903 to 5906. Figs. 5903, 5904, are a vertical section of the press with an elevation of the pumps; Fig. 5905 a sectional plan of the press with a plan of the pumps; and Fig. 5906 a longitudinal section through the press-boxes. The double hydraulic press consists of two distinct presses A and B, supplied by two pumps C and D, one of which C is 2½ in. diameter, and the other D 1 in. diameter, both connected to each distinct press-cylinder by means of hydraulic tubing E. The stroke of each pump is 5 in., and they make thirty-six strokes a minute; the larger pump C is weighted to 740 lbs. on the square inch, and the smaller D to 5540 lbs. a square inch. The diameter of the press-rams F, Fig. 5906, is 12 in. and the stroke 10 in. Each press is fitted with four boxes G, G, and receives four bags of seed in the spaces H, H, producing in all a weight of 64 lbs. of cake at each operation. After the heated seed has been removed from the heating kettle and placed in the canvas and hair bags, which is done as speedily as possible, so that it may retain its heat, the attendant first fills one press A, and opens the communication between the large pump C and the charged press A by means of the valves I, which causes the ram to rise until there is a total pressure of about 40 tons exerted on the press; the safety-valve connected with the large pump C then rises, and is kept open by means of a small spring catch. Whilst this operation is going on in the first press A, the second press B is being filled in the same manner; the communication is then opened between the large pump C and the press B by means of the valves I, the safety-valve of the pump C having been replaced in its original position; the ram of the second press B is then raised to a corresponding position with that of the first press A, when the safety-valve of the pump C rises a second time. The communication between the large pump C and the press B is then closed, and at the same time a communication is opened by the valves I between the small pump D and the presses; and the extreme pressure exerted by the small pump D, amounting to about 300 tons, is allowed to remain upon the rams for about seven minutes from the time that they were first brought into action; this, together with three minutes allowed for emptying and charging the press, is the full time required for expressing the oil in the most effectual manner. The oil in leaving the seed passes through the canvas bag, and then through the hair bag, where it finds a free exit at the edges; thence it runs into a channel or groove K which passes round the upper portion of each press-box G; a communication is made from one box to another by means of piping L, so that the oil passes from the upper boxes through the lower ones, and thence into the cistern, which is called the spell tank, being just large enough to hold the produce of one day's work. These presses are not worked with water; it has been found that oil which is not of a glutinous description works much better, and keeps both the pumps and presses in a better condition. It is scarcely possible, if the presses are properly constructed, that they should meet with any accident; this can

only occur where through carelessness an excessive weight is placed upon the safety-valve levers, or where the valves themselves are allowed to stick through want of cleanliness, from the attendant not taking care to remove the oil which sometimes becomes clotted round the valves. Each of these presses is capable of producing 36 cwt. of cake a day of eleven hours, and the yield of oil may be taken at about 14 cwt. in the same time; this of course depends much upon the nature of the seed. The cake is trimmed or pared at the edges by means of a small paring knife, after which it is put into a kind of rack to allow it to cool and dry, so that it will not become mouldy when stacked. The oil is pumped from the spell tanks into larger tanks, capable of holding

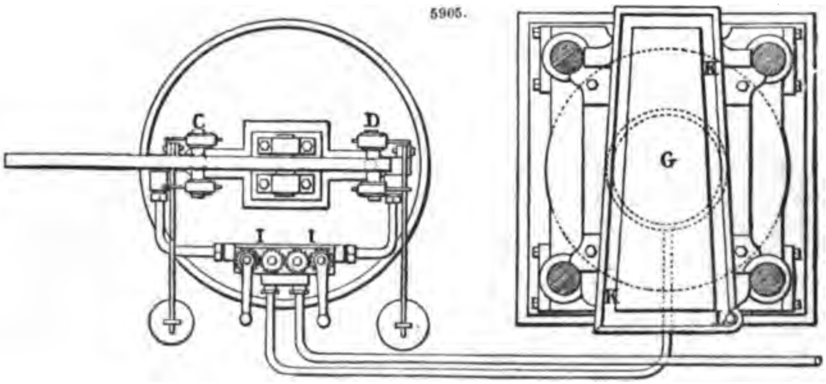
5903.



5904.



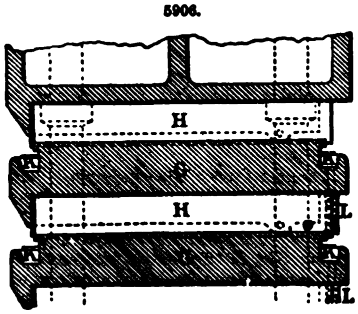
5905.



from 25 to 100 tons, where it is allowed to remain for some time for the purpose of settling, previous to being brought to the market in that condition, or to undergoing various other processes such as refining.

Figs. 5907, 5908, are an elevation and plan of a linseed-oil mill, by Martin Samuelson and Co., Hull. The whole of the machinery is driven from one main shaft, turned by a vertical steam-engine at one end. The preliminary process of shaking is here dispensed with, and the raw linseed, from St. Petersburg, weighing 52 lbs. a bushel, is in the first place passed through a pair of metal rollers 22 in. in diameter and 18 in. long, which are capable of rolling or crushing flat three quarters of seed an hour. For grinding, two stones are employed, of Derbyshire greystone, 7½ ft. in diameter and 16 in.

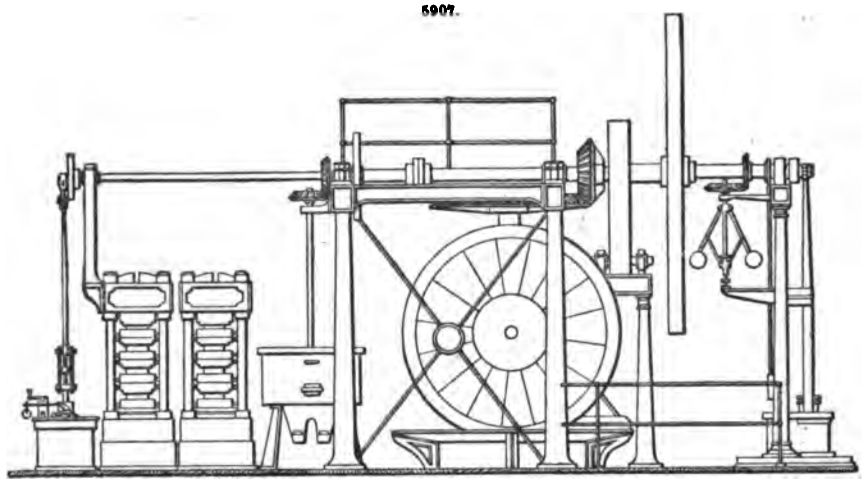
5906.



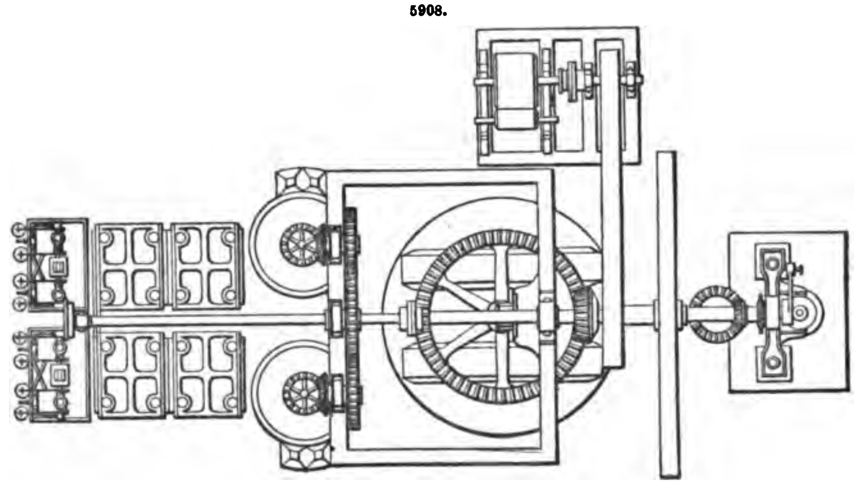
thick, bevelled off at the edges to 12 in. broad, and weighing 5 tons each; they run on a stone bed, with an iron rim or trough, which revolves and turns the stones on their axes, and round the vertical axis of the trough.

In the next or heating process, the kettles into which the seed is placed are constructed with steam-jackets or casings, from which they and their contents are heated to 90°, the seed being stirred by blades revolving on vertical axles. The bags into which the seed is measured from the kettles hold 10 lbs. of seed each, the horsehair wrappers into which they are deposited being 2½ ft. long. They are next placed in tiers of four bags each, in four hydraulic presses, making in all sixteen bags. The presses are worked in separate pairs, with two distinct double pumps to work them. The oil passes away by channels into the spell tank, which, as we have already stated, is just large enough to hold the produce of one day's operations. The oil is pumped from the spell tank into larger tanks, capable of holding from 25 to 100 tons of oil, where it remains for some time to settle.

5907.



5908.



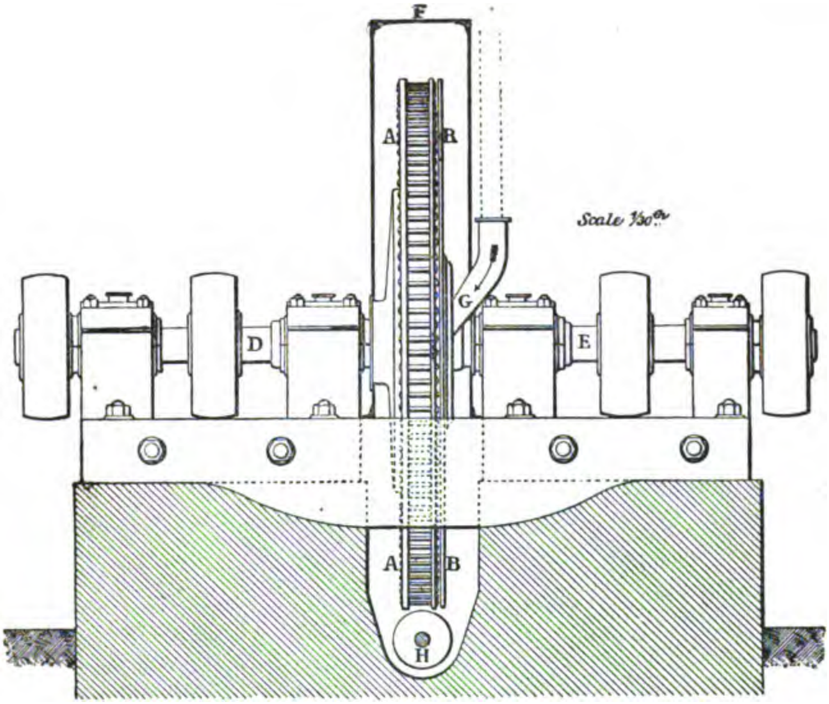
This oil-mill, Figs. 5907, 5908, is capable of crushing about 32 quarters of linseed a day of twelve hours. It produces from that seed from 4½ to 5 tons of oil-cake, and about 2 tons of oil. The total weight of the machinery is from 50 to 60 tons.

Flour-mills.—The four methods at present in use for producing flour are by the Buchholz system, the Hungarian system, by Carr's disintegrator, and by the ordinary English plan of grinding by millstones.

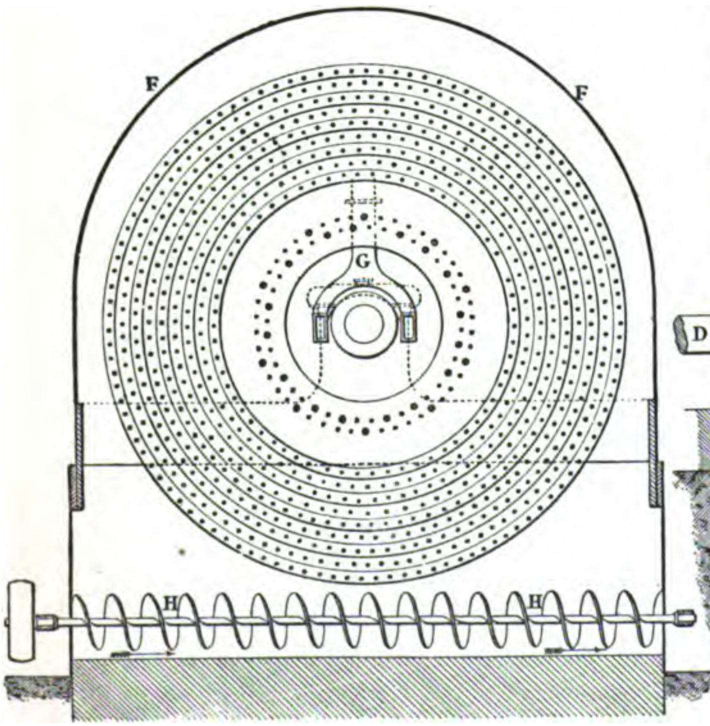
Thomas Carr's disintegrating flour-mill, as described by him before the Institution of Mechanical Engineers in 1872, is shown in Figs. 5909 to 5911; Fig. 5909 is an external side elevation of an entire machine, 7 ft. diameter; Fig. 5910 a transverse section taken through the centre of the machine; Fig. 5911 a longitudinal section of the two rotating discs with a portion of their respective shafts; Fig. 5912 shows a portion of the transverse section to a larger scale.

The machine consists of a pair of circular discs A and B, Fig. 5909, rotating in contrary directions upon two shafts D and E situated in the same line; the opposing faces of the discs are studded

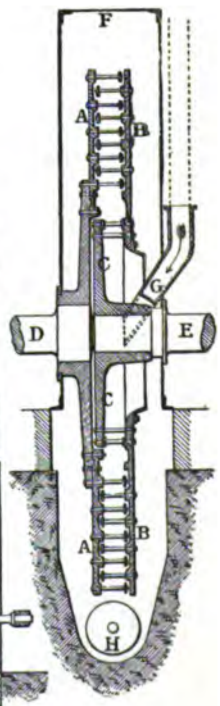
5909.



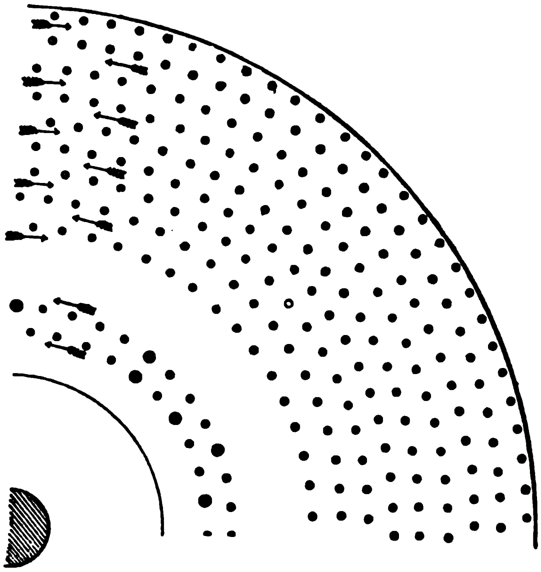
5910.



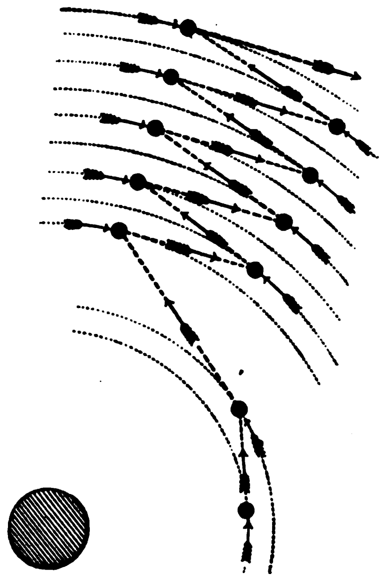
5911.



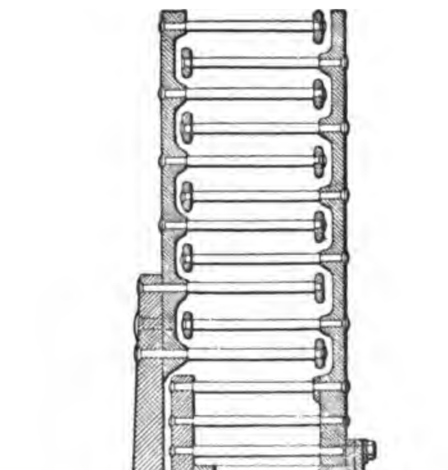
5912.



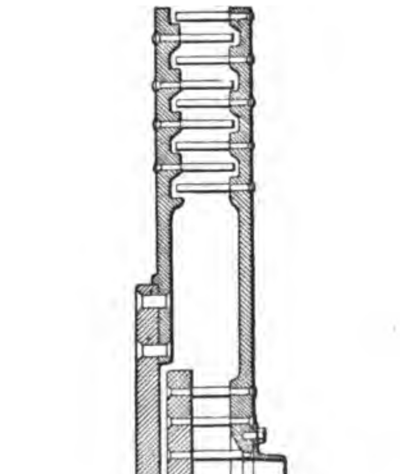
5914.



5913.



5915.



with a series of short projecting bars or beaters, arranged in successive concentric rings or cages: and the rings of beaters fixed in one disc intervene alternately between those fixed in the other disc, and revolve in the opposite direction. The solid circular disc A, keyed on the left-hand shaft D, Fig. 5911, carries the third cage or ring of beaters, counting outwards from the centre, and also the fifth, seventh, ninth, and eleventh cages, all of which therefore rotate the same way. On the right-hand shaft E is keyed a small inner disc C, into which are riveted the bars of the two innermost cages of beaters, their other ends being riveted into the right-hand annular disc B, which is thus carried by them; this annular disc in turn carries the fourth, sixth, eighth, and tenth cages, which with the two innermost all rotate in the contrary direction to the cages carried by the left-hand disc A, as indicated by the arrows, Fig. 5912. The two innermost cages are both fixed in the same disc, so as to rotate both in the same direction, in order thereby to ensure distributing the material more effectually through the machine by the centrifugal force. The cages of beaters are of successively increasing diameters, and consist of ½-in. round steel bars, with clear spaces between of about 2 in. in each direction; the outer ends of the bars in each cage are tied together by a ring, shown in Figs. 5910, 5911, and to a larger scale in Fig. 5913.

The two shafts D and E are placed in a line, their rounded ends just touching each other, or nearly so, in the centre, Fig. 5913; everywhere else ample clearance is allowed for enabling the two halves of the machine to rotate entirely independent, acting only in unison as auxiliary to each other in pulverizing the material that is being operated upon. The shafts are each mounted in two plummer-blocks on a heavy square bed-plate; and a driving pulley is keyed either in the middle of each shaft or at its outer end, as may be found most convenient for the driving straps, one of which is a crossed strap and the other an open one, so as to drive the two halves of the machine in opposite directions. The revolving cages of beaters are enclosed within an external casing F, Figs. 5909 to 5911, which has a centre opening in the right-hand side. corresponding with that of the annular disc B.

The grain is delivered down a fixed shoot G, Figs. 5909, 5911, through the centre opening of the outer casing, into the innermost cage, from which it is instantly projected through the machine, and delivered in a radiating shower from every portion of the circumference into the outer casing, in the form of meal, similar to that thrown out by the ordinary millstones; to this state the grain is reduced almost instantaneously by being dashed to the right and left alternately by the bars of each of the successive cages revolving in opposite directions at a very high speed. As it falls to the bottom of the casing, the meal is continuously removed by the ordinary rotating screw H, Fig. 5910, used in flour-mills; it is then passed through the usual bolting machines to separate the bran, and subsequently through silk dressing-machines to separate the fine flour from the semolina. The latter is then winnowed by an exhaust current of air in a machine for that purpose, so as to free it from all finely-powdered bran, and is afterwards ground between millstones, of which three or four pairs are kept for the purpose; the flour resulting from it is added to the fine flour produced at the outset by the disintegrating flour-mill, and to ensure perfect intermixture the two are then passed through the silk dressing-machines together.

The course of a particle through the disintegrator is illustrated in the diagram, Fig. 5914; the circular arrows show the reverse direction in which the alternate cages rotate, and the straight arrows at different angles show the zigzag course of a particle of material as it flies off at a tangent from each cage, being struck alternately to the right and left, and projected thereby at a speed equivalent to that at which the bars of the cage last striking it were rotating; the force of each blow is thus increased by the momentum of the material, which is moving in each case in an opposite direction to that of the beaters it next meets with. As the material becomes more finely pulverized in its course outwards through the machine, and the particles have consequently less inertia of themselves to act as an abutment for receiving the blows of the beaters, a greater force of blow is necessary, in order to continue the pulverizing process. This increased force is supplied by the higher velocity arising from the larger diameters of the successive rings of beaters which the material meets with in its passage outwards. The machine is driven at a speed of about 400 revolutions a minute; and the outermost ring being 6 ft. 10 in. diameter, the last beaters have a velocity of 140 ft. a second, or about 100 miles an hour; this is double the velocity, and consequently gives four times the force of blow of the innermost ring of beaters, the force of blow being proportionate to the square of the velocity.

In this mode of action, by the free blows of the beaters upon the material, the friction and compression between the machine and the material, which are involved in all grinding, crushing, or stamping processes, are avoided, this mill being the only machine that does not act upon the material between a pair of surfaces; and as the beaters do not strike upon any solid abutment, the whole power employed is usefully expended in pulverizing the material, excepting only the portion of the power absorbed by the resistance of the air to the rotation of the beaters. This mill has the advantage of unusual freedom from risk of injury by the accidental introduction of any unsuitable substances, such as pieces of metal; any such substances are freely ejected by the centrifugal force, without the possibility of any squeezing action being exerted upon them. The machine has not any tendency to become choked, nor are any working parts liable to get out of order, as the two sets of beaters revolve entirely clear of each other, and the beaters never come in contact with anything but the free particles of the material that is being pulverized. The beaters being of steel, and coming in contact only with the grains of wheat, are not subjected to any perceptible wear, and keep at work continuously without ever requiring any dressing or attention. But with the ordinary millstones, a surplus supply of stones, amounting to one-eighth of the whole number, has always to be kept out of work, to allow for the dressing and sharpening which is usually required to be done upon each pair of stones after about every four days' work.

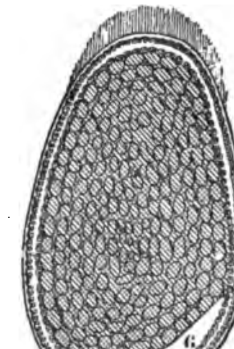
Two of these disintegrating flour-mills in regular work for twenty-two hours a day at the Bonnington Mills of Gibson and Walker at Edinburgh have proved successful during a year's continuous work.

The work regularly got through by each machine of 7 ft. diameter amounts to 20 quarters of wheat or 160 bushels an hour; which would require as many as twenty-seven pairs of ordinary millstones in full work, taking the average duty of each at 6 bushels an hour. A further supply of three or four pairs of stones under the dresser's hands would be required for keeping that number at work; but these are compensated for by the three or four pairs of finishing stones which are used with the disintegrating mill for grinding the granular portion called semolina, as before explained.

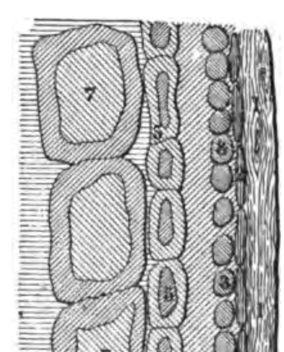
The disintegrating flour-mills at present in use are made with fourteen rotating cages, as in Fig. 5913, instead of only eleven cages, as in Figs. 5909 to 5911; but the fourteen have been found to be more than are necessary, while one mill also in use that has only eight is found scarcely sufficient. The beaters are also made much shorter now than those hitherto used, being only 3 in. long in the clear, as in Fig. 5911, instead of 8 in. as in Fig. 5913, in order to bring the discs so much nearer together, and diminish proportionately the loss of power in churning the air, which was found in the experiments made at Edinburgh to be more serious than had been at all anticipated. The capacity of the machine with the reduced width will still be far beyond the requirements, when operating on only 20 quarters of wheat an hour; for the velocity of the material in passing through the mill is so great that a mere fraction of a second elapses from entrance to exit of any given particle, and hence there can never be more than a few handfuls of the material in the machine at any one instant. In other new machines at present making, the bars being now but little more than mere pegs, the tie-rings at their extremities are dispensed with, Fig. 5915, being no longer necessary for so light and small a material as wheat. By the omission of these tie-rings the successive circles or cages of beaters can be placed much nearer the circumference, whereby their respective diameters, and consequently their speeds in feet a second, are proportionately increased. The machine is remarkable for its simplicity of construction and non-liability to deteriorate in efficiency in consequence of wear, and for its large production and the superiority of its work; and also for the very small space it occupies, in comparison with that taken up by the twenty-seven pairs of ordinary millstones which are required to perform the same amount of work.

Buchholz Process.—In order to render clear the operation of the Buchholz machines, states W. Proctor Baker, to whose paper in the Proceedings Inst. M. E., 1872, we are indebted for our information respecting this process, a brief description is desirable of the nature and structure of the grain to be dealt with. The covering or skin of the wheat is composed of three different layers or coats, as shown in the magnified diagrams, Figs. 5916, 5917. Within these is the true grain, consisting of the central floury body of the corn, the germ or embryo, and two membranes. The central body of the corn is built up of minute flour-cells of irregular shapes; and all the other portions of the grain together compose the bran. The three outer coats and the outer of the two membranes are composed principally of ligneous tissue, and constitute 3 to 5 per cent. of the whole grain.

5916.



5917.



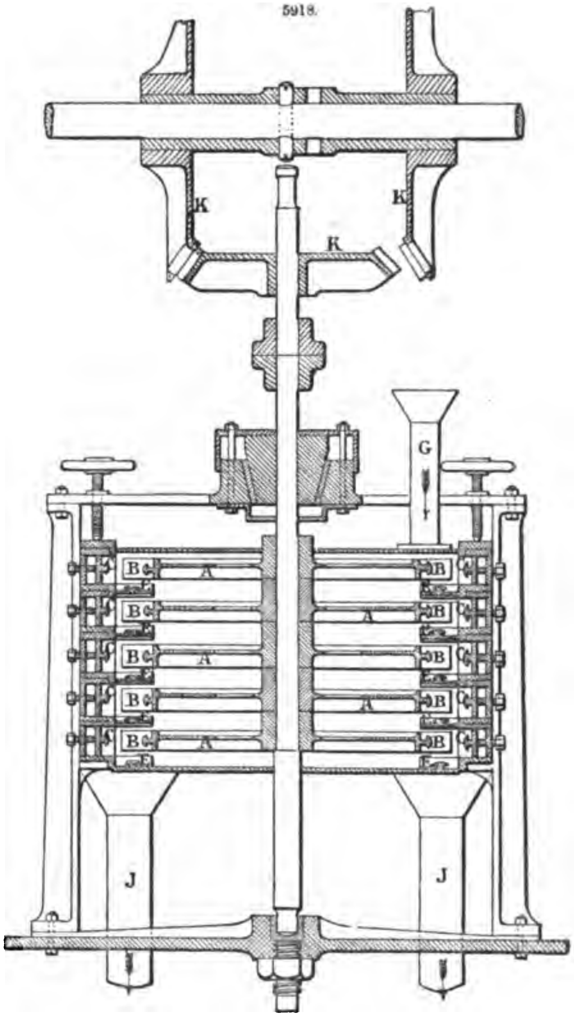
Literal Reference;—1, Epidermis; 2, Epicarpis; 3, Endocarpis; 4, Testa membrane; 5, Embryo membrane; 6, Embryo. These form the Bran,—7, Perispermum;—Flour-cells.

The inner of the two membranes surrounding the floury body of the grain contains in its cells the principle named cerealine, which was discovered some years ago by the French chemist, Mège-Mouriès, by whom it has been shown that the good or bad colour, the fineness of texture, and even the flavour of bread, depend upon the absence or presence of cerealine in the flour, and that flour not containing cerealine makes better bread than flour in which it is present. Practically, flour containing cerealine produces bread of a brown colour, and the bread becomes browner as it becomes stale; while flour free from cerealine produces white bread, which retains its colour unimpaired for a length of time. Cerealine is believed to exist in all parts of the grain, and it varies in colour according to its position in the corn; but the most noxious cerealine is contained in the cells of the innermost membrane, and its dark black character is rendered apparent by mixing bran with white

flour; the result in baking is not, as might have been expected, white bread with flakes of bran in it, but a distinctly brown loaf. The flour from the centre of the grain is the finest and best, that obtained from the layers near the membranes is inferior.

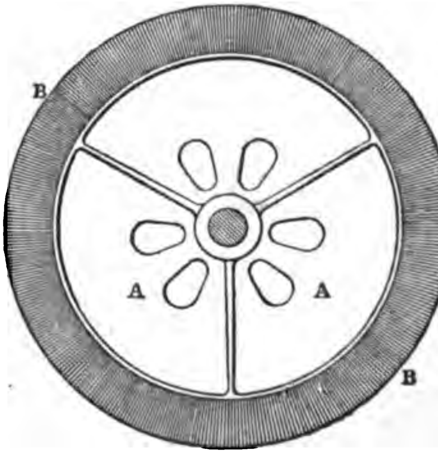
The object of the Buchholz process is to produce what may be termed true flour, that is, the substance contained in the central body of the grains of wheat, so extracted from them that it is free from any admixture of the coats, and as free as possible from cerealine, and is in a fine granular state, not crushed to powder by pressure or smashing. In contrast with this pure substance, the flour of commerce is really a fine meal, consisting of a mixture of true flour, bran, and dust; and there are no means in existence by which these various substances can be separated after once they have been mingled together. The object to be attained in the Buchholz system is therefore to remove so much of the coats of the grain as can be taken away without risk of injuring or removing any portion of the more valuable substance of the interior. There is no reason why the attempt should not be made to strip the coat off the grain by the same process by which the interior portion is reduced to flour, and at the same time at which the reduction is effected. To accomplish the process of decortication numerous plans have been tried, and many different machines invented, some of which have done their work well for a time; but sooner or later the grain operated upon has proved too strong and hard, and the machines, if their work was perfectly done, have always worn out, whatever their construction, or whatever the materials of which they were made.

5918.



The hulling machine, Figs. 5918 to 5920, has been invented and constructed by Buchholz to overcome these difficulties; and after considerable experience it has been found to do its work with thorough efficiency, and to stand the test of wear. It consists of a series of revolving cast-iron discs A, fixed on a vertical spindle, making about 350 revolutions a minute, and furnished all round the circumference with thin hard steel blades B, set radially and at right angles to the plane of the disc. These blades, of which there are twelve to sixteen to the inch, are separated by pasteboard packings a little smaller in width and length than the blades, so that the edges of the latter project, as in Figs. 5921, 5922. In the course of time the steel blades wear down, so that their edges become level with the pasteboard packings, and these are then cut away in order to expose again the edges of the blades. The discs revolve within a cylindrical casing, which is lined on two opposite sides with steel blades C, C, Figs. 5918, 5920, similar to those on the discs, a clearance of $\frac{1}{8}$ to $\frac{1}{4}$ in. being left all round the

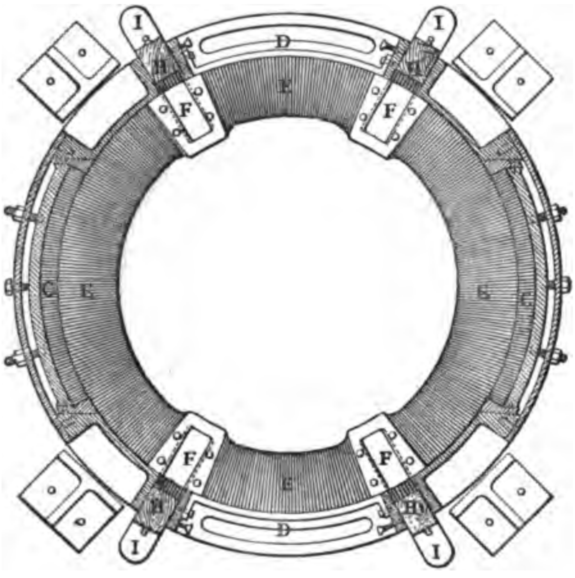
5919.



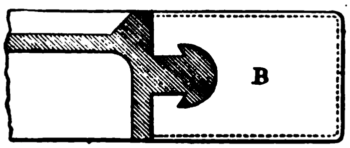
discs; and the casing has open wirework D, D, in the two intervening portions of the circumference, Fig. 5920. Between each revolving disc is a fixed annular disc E, furnished on its upper side with a similar arrangement of steel blades, and situated just below and above the circle of blades in the two adjacent revolving discs, thus dividing the machine into a series of horizontal compartments. Holes F, F, are made at intervals in the annular discs, and are closed to any required extent by regulating slides I, I.

The grain, fed in through a pipe G in the cover of the machine, Fig. 5918, passes down between the edge of the blades B on the first revolving disc and the fixed blades C and E in the casing; and then passes down through the holes F into the next compartment below, and so on through the successive compartments to the bottom. A portion of the skin is removed from the grain by the action of each revolving disc, and the particles cut off escape through the wirework portions D, D, of the casing, Fig. 5920, a constant current of air being made to pass down through the machine for aiding their removal. The regulating slides I closing the holes F in the fixed annular discs, Fig. 5920, afford the means of retaining the grain a longer or shorter time under the action of the blades in each compartment of the machine, and brushes formed of plates of sheet india-rubber are inserted in the casing at H, H, for pressing the grain close up against the revolving discs. The cleaned grain is delivered at the bottom of the machine into the spouts J, J, Fig. 5918. The machine being built up of a series of compartments, all precisely the same, its cutting power can at any time be readily increased or diminished according to the nature and quantity of the grain under treatment, by increasing or diminishing the number of the compartments.

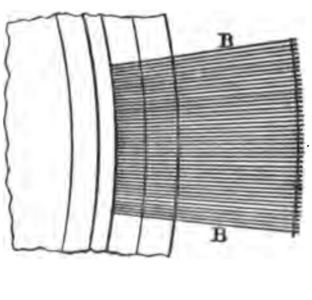
5920.



5921.



5922.



In order that the hulling machine may continue in an efficient working condition, it is necessary that the edges of the blades should always be sharp; and such is the hardness of the coat of the wheat grain that the keenness of edge is taken off the steel blades in a few hours; but while the sharpness is being worn off the front cutting edge of the blades, a sharp edge is being set up on the opposite side of the blades so that it is only necessary to reverse the direction in which the discs rotate in order to bring the sharpened back-edges to bear upon the grain. The machine is supplied with reversing gear K, Fig. 5918, and in practice the direction is reversed about every twelve hours, the machine being thus self-sharpening.

The cutting action of the hulling machine is perfectly under control, so that either a large or a small quantity of the skin of the grain can be removed, as desired. It is possible with this machine to remove absolutely all the brown matter from the grain, preserving perfectly the shape of the grain and making on waste of flour. Many other machines are excellent polishers of grain, removing the outer skins to the extent of 1 or 2 per cent. of the whole grain; but as these outer skins are nearly transparent and colourless, the advantage gained is not very great. What is required for real utility is that the inner membrane of the coat of the grain should be cut into, and as much as possible of it be removed. A substantial advantage is gained only by the removal of a considerable quantity of the covering, to the extent of at least 7 per cent. of the whole grain, or more; for the worst and most deleterious of the cerealine is then got rid of. The appearance of the parings obtained by the use of this huller shows the utility of removing them from the wheat. They form a dark soft greasy substance; and the presence of any of this, even the most minute portion, in flour, is ruinous to the appearance and quality of bread. It is, however, a most excellent food for cattle and pigs, and its market value is about the same as that of bran; so that there is scarcely any loss by its removal before grinding the wheat. As it is very important that the wheat should be completely freed from the most minute particles of this noxious dust, before it is ground, the

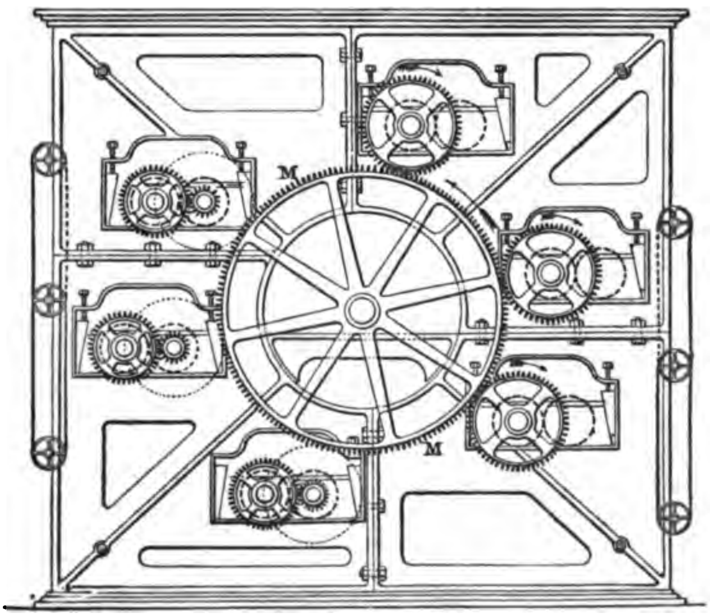
wheat delivered from the huller, with so much of the dust as has not been driven off through the wirework of the casing, is led to a separator covered with wire, to sift out every particle of dust; and it is very useful to expose the stream of wheat to the action of an exhaust fan, to carry away any floating particles.

The hulling machine occupies little room; it requires little attention after it has once been set properly to work, and it will work for twelve months without requiring repairs; when worn, all that is wanted is a new set of blades, which can be refitted expeditiously and cheaply. The power required to drive the huller varies with the description of the wheat passing through it; about 10 to 12 horse-power is required to drive a machine that will decorticate about 4 to 5 quarters of wheat an hour. The whole of this power, however, is saved in the subsequent grinding process, if the wheat be ground in the decorticated state; for having then been deprived of its hard tough skin, it breaks down far more easily than wheat in the natural state, and a pair of millstones grind a far larger quantity an hour, and require much less power to drive them. The commercial value of the operation of this hulling machine varies with the quality of the wheat used. The worse the wheat, generally speaking, the more is it improved by this process; and the very brown Danube, Banat, and Russian wheats are those upon which the greatest gain accrues. On the better qualities —American, Baltic, and other red wheats—the advantage is less, and with fine white wheats it is least. The superiority in quality of the flour produced is not only in its colour, but also in its smoothness of texture and strength; and the hulling machine is therefore by itself of great value, even in cases where the wheat is ground at once on leaving the huller, without undergoing the further process about to be described.

The hulling machine is not intended to remove the whole of the interior membranes of the grain, for if that were done, the central flour-globules would be exposed to the action of the blades, and a portion of the best part of the corn would be cut away and mixed with the worst part. The next object, therefore, is to separate the central portion of the corn from the remaining membrane; and the most simple way would appear to be to scrape this fine internal portion off the membrane, leaving the cells containing the cerealine undisturbed in the form of bran. This is what is accomplished in the next stage of the Buchholz process; the grain is ripped open, and the flour-cells are torn and scraped away from the bran.

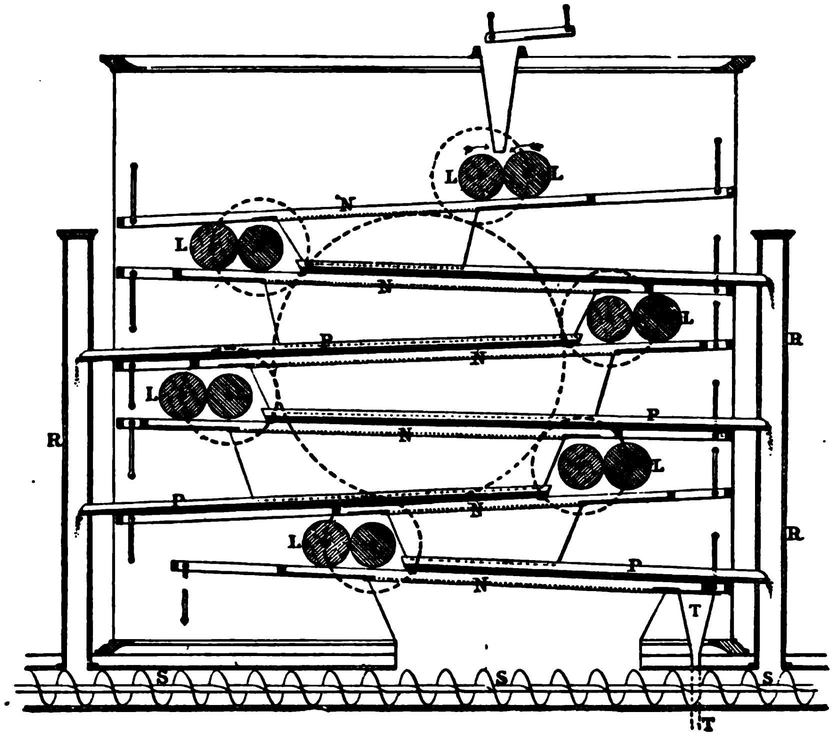
Figs. 5923 to 5926 are of the semolina mill, by which these operations are performed; semolina signifying a material which has been half ground. The chief feature of the machine is that its operations are effected by a series of pairs of grooved steel rollers L, L, running at differential speeds; these are shown to a larger scale in Figs. 5927, 5928. The first pair of rollers, at the top of the mill, do that which has been described as ripping open the grain; and for this purpose the surface of each roller is cut into diamond points, nine to the inch, as shown full size in Figs. 5929, 5930. The remaining pairs of rollers are all intended by cutting and scraping to tear away from the bran the interior portions of the grain. These rollers are therefore grooved longitudinally, as shown full size in Figs. 5931, 5932; there are eighteen grooves to the inch in the upper rollers, and the lower ones are gradually finer grooved, up to twenty-eight to the inch.

5923.



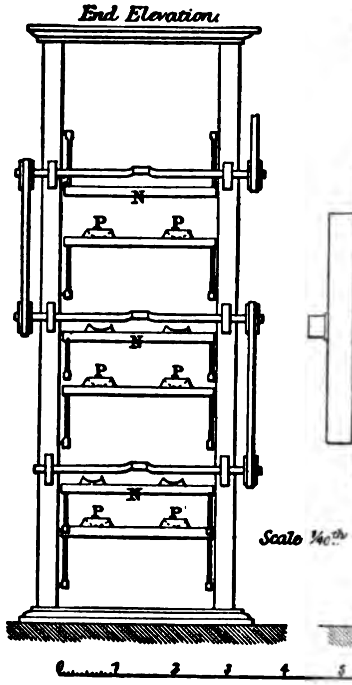
The best arrangement of this mill is to place the rollers as in Figs. 5923, 5924, so that the fast rollers of each pair can be driven from central shafts by spur-gearing M, the slow roller of each pair being driven through spur-wheels by the fast one at exactly one-third the speed; and the slow roller

5924.



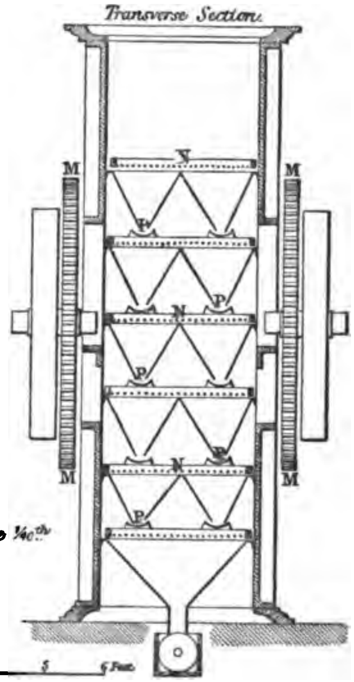
5925.

End Elevation.

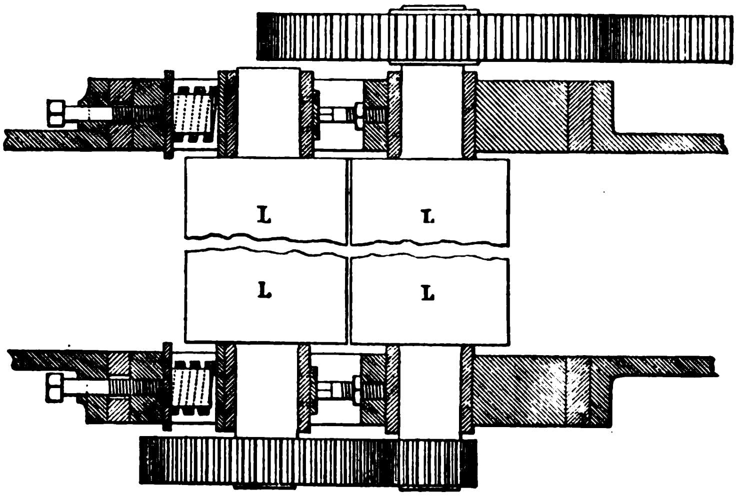


5926.

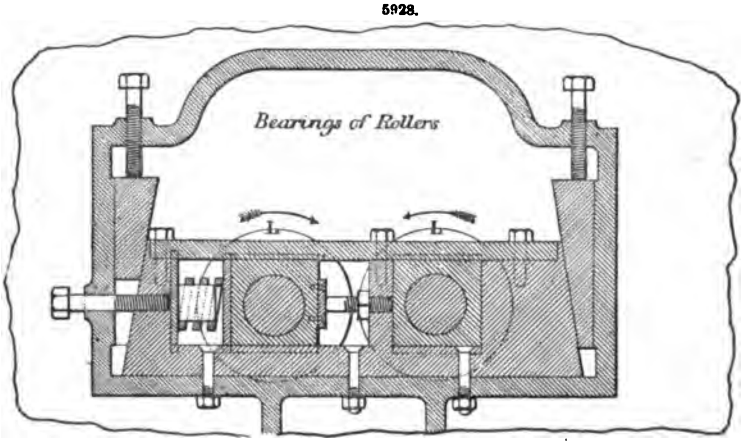
Transverse Section.



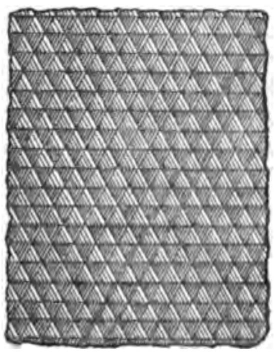
5927.

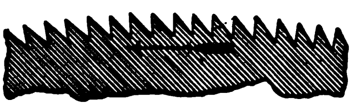


5928.



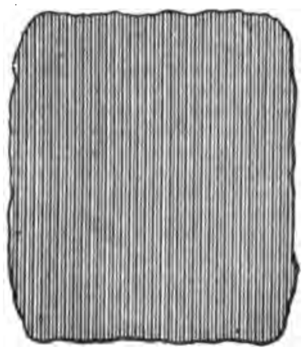
5929.

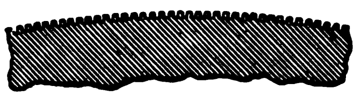




5930.

5931.





5932.

in each pair runs at from 100 to 110 revolutions a minute. Under each pair of rollers is an oscillating sieve N, Figs. 5924 to 5926, to receive the stuff which has passed between the rollers; the semolina and flour scraped off by the rollers pass through the sieve, while the larger bran passes over the tail of the sieve to be further scraped again by the next pair of rollers, and so on through the whole series. The semolina and flour passing through the sieves fall into the troughs P underneath, and are delivered by the spouts R to the traversing screw S at the bottom of the mill, by which they are conveyed away to the dressing or sorting reels. The bran finally discharged from the tail of the bottom sieve is conveyed away separately by the spout T.

Semolina is produced on the Continent by breaking down wheat between millstones kept at such a distance apart that they cannot reduce the grain to flour at one grinding. The grinding has therefore to be repeated several times before the semolina can be detached from the bran; and then by a laborious process of sifting by hand labour or by ventilation the semolina is separated from the bran. The objection to this plan is, that while only a small proportion of semolina can be obtained by it, a considerable quantity of flour of very poor quality is unavoidably produced, its inferior quality being due to its being mixed with the very small and fine particles of bran which have been chipped off in grinding; and these particles of bran contain the most considerable portion of the noxious cerealine. At the same time, the pressure necessarily employed in grinding has the effect of crushing some of the flour-globules to dust, which is the most certain method of destroying their good qualities for bread-making. The millstone is indeed but a blunt instrument, and can do its work, like a blunt knife, only when assisted by considerable pressure.

By the employment of the fluted steel rollers, rotating at a considerable velocity and at differential speeds, while fixed at a definite distance apart, the sharp keen edges of the flutes on the fast roller act as a series of cutting blades, while the slow roller holds the material, but at the same time passes it forwards. The crushing action of millstones being thus avoided, a large percentage of semolina is produced, with only a small proportion of flour, the whole of the work being done by sharp cutting edges. The Continental system of grinding can be remunerative only in countries where a demand exists for the large quantity of inferior flour produced in the operation of grinding wheat into semolina, and where at the same time a very high price can be obtained for the beautiful flour which the small relative quantity of semolina yields. In making a comparison with the Continental system of grinding, it must be remarked, moreover, that the only kinds of wheat which yield semolina under the millstones are those of peculiar semi-brittle quality; while tender mellow wheat gives no semolina, as its floury portion is pulverized at once into flour by the rubbing and crushing action of the stones. On the other hand, by the Buchholz process, the whole principle being that of using a cutting instead of a crushing action, a large percentage of semolina is obtained from even the most tender native wheat, which would yield no semolina under the millstones.

The bran as discharged from the rollers in this process at T, in Fig. 5924, is thick, and by no means merchantable, for it has not been sought to cut away from it the whole of the flour-cells next to the membrane, because it is desired to leave the noxious cerealine undisturbed. The bran may be ground through millstones, and the flour obtained from it may be dressed out in the ordinary way; but as would be expected, however finely this flour is dressed, it will nevertheless bake brown, as it is the worst flour the grain contains; and the fact that it is so is the very reason why it should be kept apart by itself. The remaining produce of the semolina mill goes all together into the trunks R, R, and consists of semolina large and small in size, the small pieces of bran of the same size as the semolina, and the flour which has been made by the rollers. The quantity of this flour should not exceed about 5 per cent. of the original wheat, and its quality is better than the flour made from similar wheat by ordinary millstones. The whole produce, except the bran, is taken to a silk reel, where the head silks dress out all the flour, and the silks at the tail take out the finest semolina or sharps.

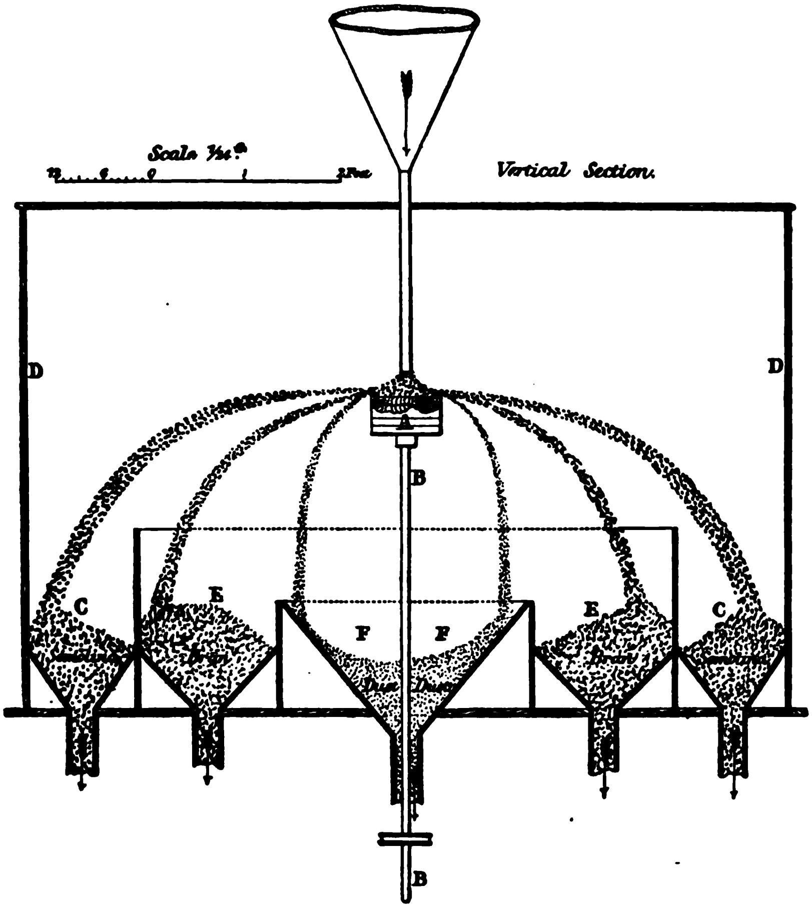
The remaining larger sizes of semolina and the bran of corresponding size are passed over a silk which sorts them into three sizes, and each of these is then freed from the small bran contained in it by the centrifugal separator shown in Fig. 5933. A small horizontal wood disc A on the top of a vertical spindle B is made to revolve at such a speed as will throw the semolina to the sides C, C, of a cylindrical case D. The bran being lighter cannot be thrown so far, and thus falls into an inner annular division E E of the case, while the fine dust falls into the centre compartment F; and all are collected separately on a lower floor from the spouts. The speed of the disc A in the separator, Fig. 5933, varies, according to the size of the semolina, from 250 to 650 revolutions a minute. The semolina is then fit for the millstones, to which it can be led either mixed or each sort by itself, the flour being afterwards dressed out.

Where there are no millstones, a roller mill may be used to reduce the semolina to flour, consisting of rollers of the same kind as those used in the semolina mill, but with a much finer grooving. The result, says W. P. Baker, is a large percentage of flour of great beauty and bloom, quite different in appearance from anything that can be produced by the ordinary grinding with millstones, however finely such flour may be dressed. In fact, however good may be the dressing, it is impossible by that means to restore to flour the properties it has lost by bad grinding. By the roller process, flour can be made from wheat of poor quality, which cannot be equalled in grinding by millstones, even if the finest wheat be used. The roller mill is equally adapted to all kinds of wheats, but the gain is naturally greater with coarse red wheat, containing, as this does, much brown matter. Many descriptions of red wheat are sound and strong, and have no drawback but the bad colour of the flour they yield under the old plan of grinding by millstones, and they may always be bought at a low price. But with the roller mill, such wheats as some of the Banats, Hungarian, and Black Sea, produce flour which is better and whiter in bread than any that can be obtained by millstones from the best white English wheat. It is found, moreover, that flour freed from cerealine produces about 10 per cent. more weight of bread than ordinary flour.

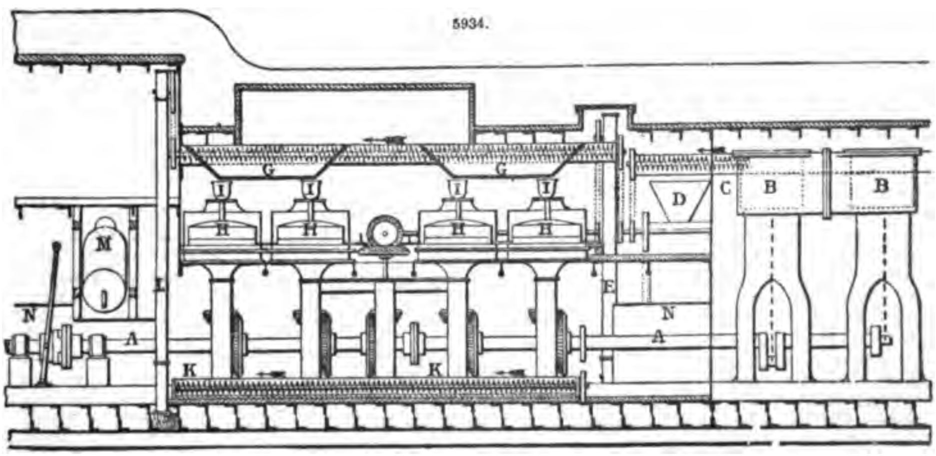
Although the Buchholz produces a beautifully white flour, the advantage of getting rid of the cerealine is much disputed.

Figs. 5934 to 5937 represent the arrangement of a floating steam corn-mill, fitted by William Fairbairn and Sons, in iron screw-steamers, and used to supply the British army during the Crimean war; Fig. 5934 is a longitudinal section of the vessel; Fig. 5935 a plan of the machinery, with the decks removed and partly in section; and Figs. 5936, 5937, transverse sections of the vessel.

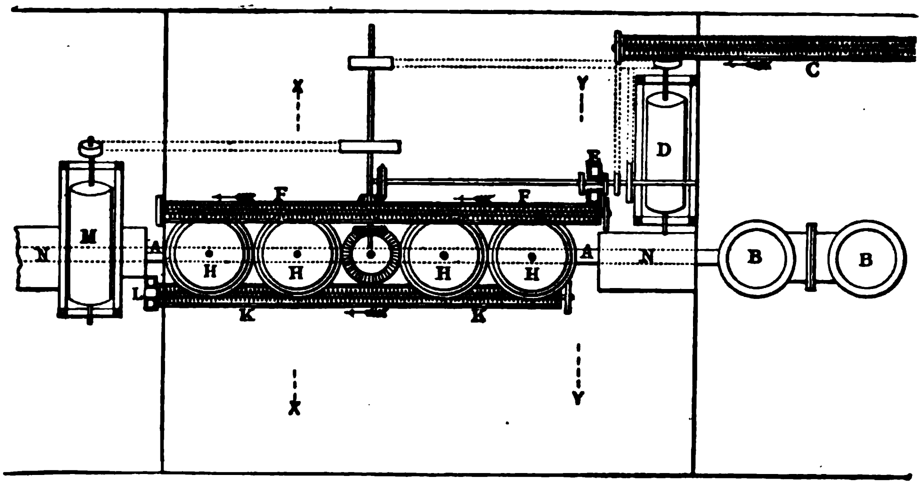
5933.



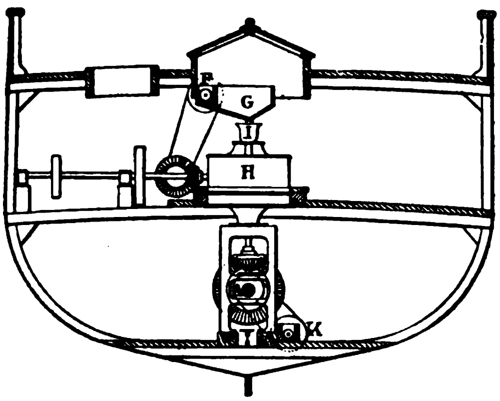
5934.



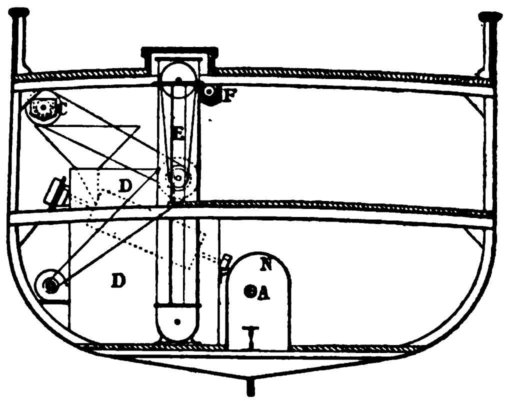
5935.



5936.



5937.



The mill machinery is all driven from the propeller-shaft A, operated by the engines B; and the whole of the processes are performed without the aid of manual labour. The wheat is stored in the fore hold of the vessel, and raised by an elevator into the screw-creeper C, which conveys it into the corn-dressing machine D, where it is cleaned and winnowed. Thence it is again conveyed by the elevator E and the screw-creeper F into the hoppers G, G, for feeding the millstones H, H. The grain is fed to the stones by the silent feeders I, first introduced by William Fairbairn, and now in general use in this and foreign countries. After being ground by the millstones H, the flour or meal is delivered into the screw-creeper K, which conveys it to the elevator L, by which it is delivered into the flour-dressing machine M; it is here freed from bran and filled into sacks, having been separated into a fine and coarse quality. This completes the whole process. The propeller-shaft A is exposed under the millstones, but covered by an iron trough N in the other parts of the vessel.

There are four millstones, and these utilize 20 out of the whole 80 horse-power—the horse-power of the engine.

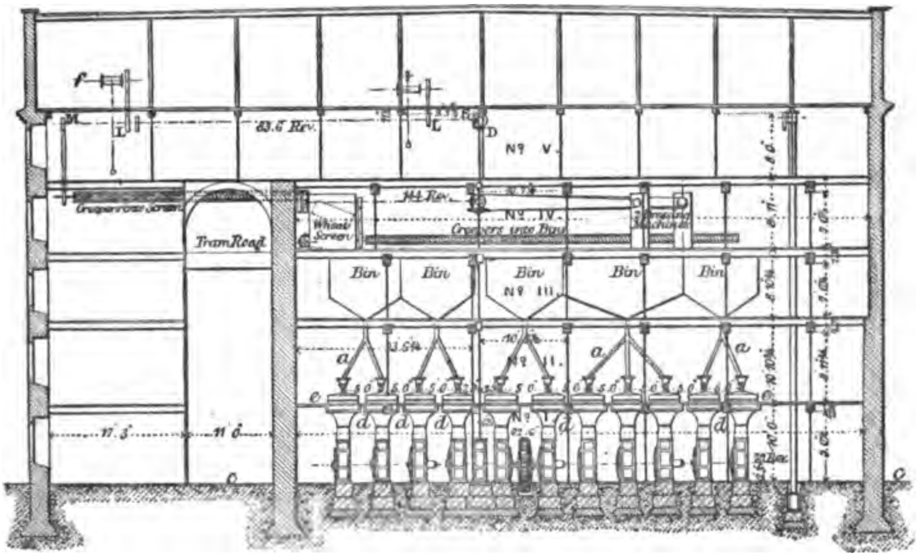
The grinding of wheat was found to be performed quite satisfactorily whilst the vessel was at sea, even in a heavy swell, causing an excessive motion, which tried the fitness of the machinery for the work to an unusual degree; the grinding whilst the vessel is performing her voyage being obtained from the same power that propels her. On one occasion when the vessel was steaming 6½ knots or 7½ miles an hour, ten sacks of 168 lbs. each, or 1680 lbs. of wheat, were ground an hour, and the mill was kept in constant work for thirty-five hours, and was found to run more regularly than when the screw was disconnected.

In the ordinary process of grinding corn, modern practice differs but little, in its main features, from that which has been in use for many centuries; the corn being caused to pass between two horizontal stones, placed nearly in contact with each other, and furrowed by grooves on their contiguous surfaces; the lower stone being immovable, while the upper revolves upon a spindle, and has a hole in its centre through which the corn is admitted. Various modifications of this method have been proposed, and, to a limited extent, adopted. None of these methods, however, appear to possess

such advantages as to justify their adoption in preference to the established practice; which, simple as it is, has yet, in its minor details, partaken so largely of the mechanical improvements of modern times, as to have changed the character of the corn-mill from a rude and unwieldy combination of timber, stone, and iron, into a highly elegant and efficient piece of machinery.

Fig. 5938 is a longitudinal section; Fig. 5939, section through engine-house; and Figs 5940 to 5942, plans of the various floors of a large mill upon the English plan, erected at Odessa by Wm. Fairbairn and Sons, of Manchester. As in most English mills of the present day, it will be seen that the pairs of stones *e*, *e*, are arranged in a single line, enclosed in iron cases, and supported on strong iron framing *d d*. The power required to drive the mill is obtained from a steam-engine *g g*, the fly-wheel *h* of which gears into the pinion upon the horizontal shaft *i i*, and the motion is then distributed on each side to the stones by bevel-wheels. The wheat, as it is brought to the mill, is first delivered in its uncleaned state into the wheat garners situated to the left of the building. From these it is passed by means of Archimedian screw creepers to the wheat screen or smut machine, where the whole grain is cleaned and separated from dust, seeds, and foreign substances

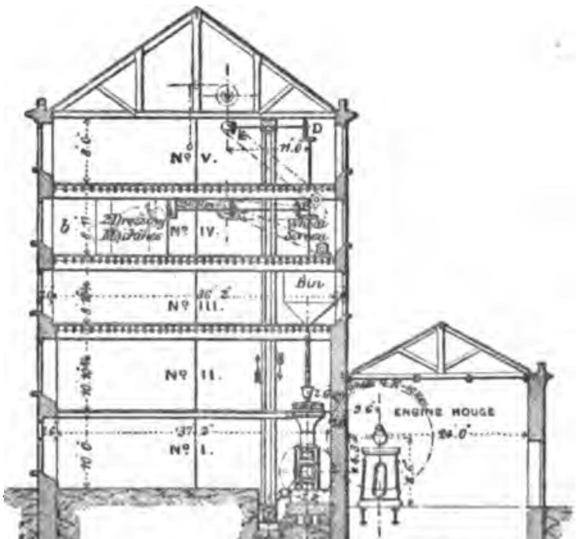
5938.



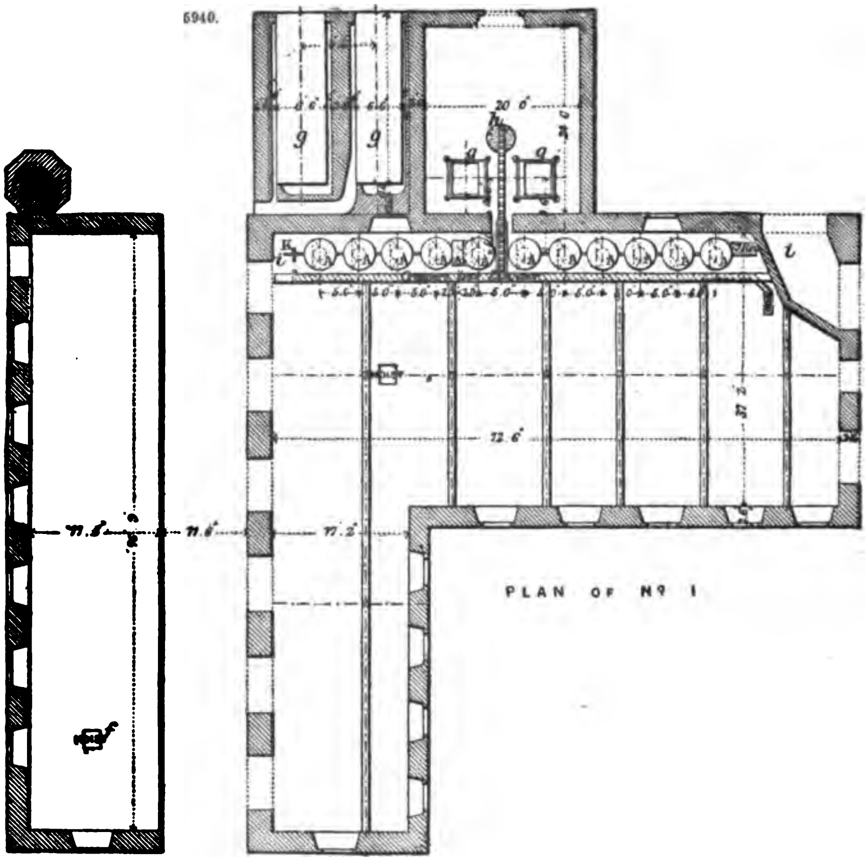
and whence it is distributed by other creepers into the clean wheat bins; from these it passes by the feed-pipes *a*, *a*, to the feed-hoppers of the stones, where it is ground.

Considerable difference of opinion exists among the millwrights of the present day regarding the comparative advantages of spur and bevel gearing as employed for driving grinding machinery. When spur-gearing is employed the arrangement is as follows; a great spur-wheel, fixed upon a vertical shaft driven by bevel-gearing from the prime mover, revolves in the centre of a system of stones, the number of which rarely exceeds six; each of these is driven by a pinion gearing into the great spur-wheel, which thus commands the whole simultaneously. Into this question our limits do not admit of our entering; in our examples we have chosen the latter method, as being that most generally practised. We may, however

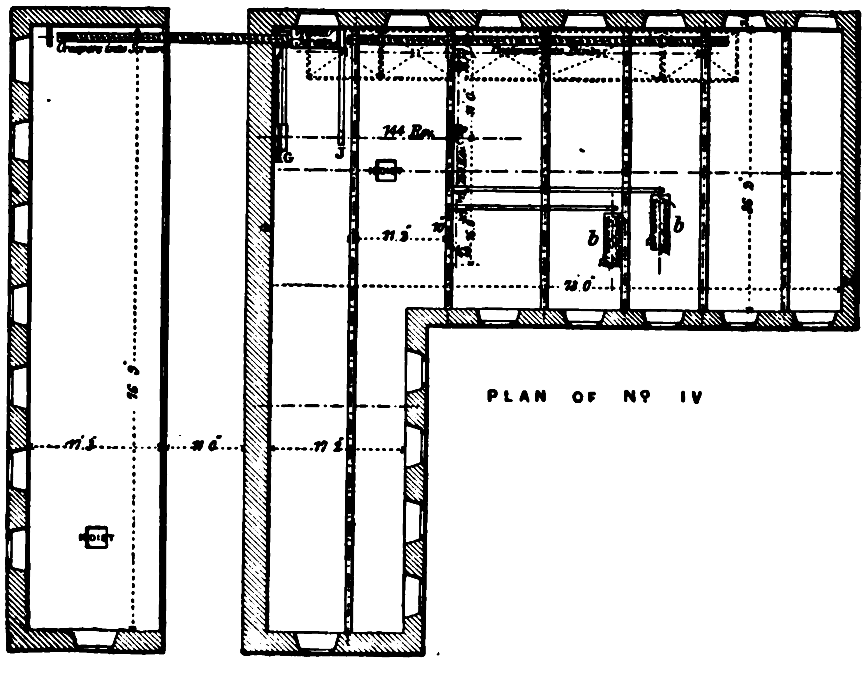
5939.



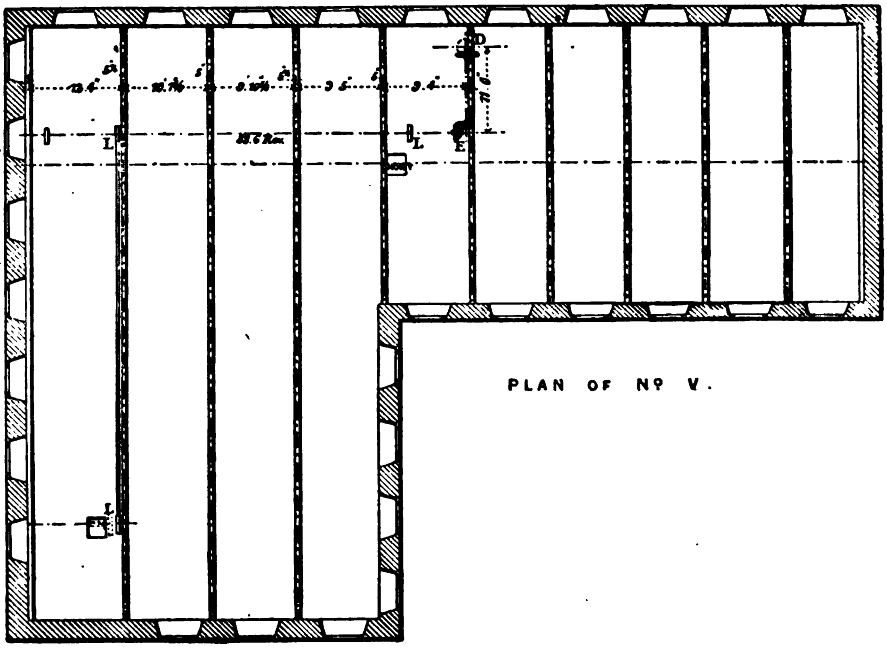
5940.



5941



5942.



be permitted to enumerate a few of the more obvious advantages attending the present system. 1st, it admits of the stones, whatever may be the number employed, being ranged in a straight line instead of in a circle, thereby economizing space and tending to a more convenient and economical disposition of the garners and apparatus by which they are fed. 2nd, it dispenses with the cumbrous and expensive framework necessary for binding together the parts of the system of spur-gearing. 3rdly, it admits of the employment of wheelwork of a finer pitch, and consequently of a more smooth and equable action, than could be used in the other case. And, 4thly, the use of bevel-gearing increases the facility of disengaging at pleasure any pair of stones which may require examination or repair.

We shall now proceed to describe the mechanism by which the various processes undergone by the grain, both previously and subsequently to the grinding, are effected; and, to avoid repetitions, we shall notice these processes in the order in which they occur.

The wheat to be ground is deposited in the upper floor of the mill in the large garner, from which it is conducted through a creeper into the screening machine. This machine consists of a species of cylindrical sieve, formed of wire cloth, and partitioned inside so as to resemble an Archimedian screw. It is mounted upon an axis, and revolves with a considerable velocity in the interior of a close box, in which it is set at an angle with the horizon. The corn enters at its upper extremity, and, after being thoroughly agitated by its passage through the partitions in the interior of the screen, and thereby divested of the greater portion of the refuse with which it was mixed, falls into a spout; being subjected, in its passage through this spout, to the action of a blast from a fan, by which the remaining portion of the sand and dust that escapes with the grain is carried off by a passage leading to the exterior of the house. The grain, after being thus cleansed, is delivered into the creeper-box, by which it is distributed into the feeding bins.

The elevator consists of a long endless chain of small buckets formed of tin plate, and mounted at regular distances upon a leather band passing over two pulleys enclosed within cast-iron frames. The uppermost of these pulleys is driven at a moderate velocity by a belt, and the buckets, passing in succession the opening by which the grain is delivered from the screen, become each charged with a small portion of it; this they convey through the wooden pipes or boxes, in which they are enclosed, to the upper extremity of the chain, where they deliver their contents.

The contrivance just described is applicable only to the raising of the grain or flour from a lower level to a higher. For horizontal transport, modern millwrights make use of an apparatus called the creeper, which is a very happy application of a well-known principle to the abridgment of manual labour. The creeper is a long endless screw, with a wide pitch and thin threads, enclosed in a wooden box or trough, of dimensions slightly greater than its own diameter. It is made to revolve upon its axis, by means of a belt and pulleys, at a velocity corresponding with that of the elevators, and, being restricted from moving longitudinally, the threads of the screw force the grain introduced at one end of the trough to the other. The action of the screw in the case of the creeper is identical in its nature with that of the endless screw in giving motion to a worm-wheel.

The wheat which is supplied to the bin falls through the feeding pipes or spouts *a*, *a*, into the hoppers, by which the grinding apparatus is surmounted. After being reduced into flour, it falls through pipes, into the creeper-box, Fig. 5940, by which it is transferred to an elevator. By this

elevator it is raised to the summit of the house, and carried by means of creepers *b*, *b*, to the dressing machine.

This machine, which is very similar in external appearance to the screening machine already described, consists of a hollow cylinder, covered with wire cloth of different degrees of fineness, the finest being at the end which is most elevated. Within the cylinder, which is stationary, a circular brush revolves, in contact with the wire cloth of which it is composed. The flour which is fed into the cylinder is, by the motion of the brush, sifted or rubbed through the wire, the finest through the upper end, the second through the next division, and so on, till the bran falls through the end of the cylinder, being too coarse to pass through any of the wires. The different products thus separated are then stored in sacks, or otherwise disposed of as may be most convenient.

On the processes undergone by the corn both previously and subsequently to the grinding, much of the success of the whole operation depends. In place of the wheat screen, an apparatus called a shelling mill has been employed in some establishments. This consists of a pair of ungrooved millstones working at such a distance apart that the grain is merely rubbed between them, but not cut or broken. From the stones it is received upon an inclined sieve, where the heavier parts of the refuse fall from it, and is then exposed to the blast of a fan, which deprives it of the remaining lighter portions. For dressing the flour, bolting machines are very generally used either in combination with, or in place of, the dressing machines described above.

The Stone Framing.—A strong cast-iron standard or framing securely bolted to a stone foundation by two holding-down bolts, encloses the principal part of the driving and adjusting gearing for each pair of stones. It is made in the form of an oblong box, and is traversed by two horizontal diaphragms or partitions, cast of a piece with it, the upper one for sustaining the footstep of the mill-spindle with its adjusting apparatus, and the lower for carrying the plummer-block of the driving shaft. It is surmounted by a large bell-shaped casting, called the cone, firmly bolted, by a flange at its lower end, to the standard, while the upper extremity is expanded, and terminates in a cylinder, of a diameter somewhat greater than that of the millstones, the lower of which, sometimes called the *bed-stone*, rests, and is secured within it. Two straight and broad flanges are cast at opposite sides of the cylindrical part, for the purpose of bolting the cone to the beams of the mill, or to the same parts of the framing of the contiguous pairs of stones; while another circular flange passes all round, for sustaining the flooring. Three large openings are left in the upper part of the cone to give access to the interior, and it is provided with suitable arrangements for the reception of the several adjusting screws required for the setting of the lower stone.

The Stone Case and Feeding Hopper.—Above the cone, and of the same diameter with the cylindrical part of it, is placed the stone case, which surrounds the upper stone, and serves to confine the flour which is the result of the grinding. This is simply a cylinder of thin sheet iron, resting upon the stone floor, and having affixed to the top of it a ring of wood, on which the tripod for supporting the feeding apparatus is set. This cover is made open in order to admit the air freely between and around the stones during the process of grinding. A cast-iron ring, supported by three malleable iron legs, forms a sort of tripod in which is placed the hopper, which receives the grain from the bins above, through the feeding pipe or spout, and supplies it to the stones by means of the feeding apparatus. A piece of coarse wire gauze is placed in the hopper, to intercept any foreign body that may descend with the grain.

The Driving Gear.—The driving shaft is part of the line of horizontal shafting which is common to the whole range, and which receives its motion from the prime mover, generally through the intervention of a single pair of wheels. The velocity of this line of shafting is usually from seventy to eighty revolutions a minute, with stones of the diameter of those in our examples. The driving shaft revolves in brass bearings, fitted into a plummer-block, bolted to a sole formed in the standard. The strain of the shaft being entirely in a downward direction, this plummer-block requires no cover, the journal being simply protected from injury by a slight brass cap.

A large bevel mortise wheel, working into the pinion on the mill-spindle, serves to transmit the motion of the shaft to the latter. These wheels are made with the greatest possible care and accuracy, so as to work together very smoothly. The pinion is not fixed immovably upon the spindle, but is capable of sliding vertically upon it by means of a sunk feather.

The Mill-spindle and its Appendages.—The mill-spindle is made of the best forged iron, accurately turned over its entire length, and rises perpendicularly through the standard, the cone, and the lower millstone. It is attached to the upper or running stone by means of a cast-iron piece, called the rhind, which combines this function with that of regulating and delivering the supply of grain to the stones.

The lower or fixed stone is perforated by a large square hole in its centre, into which the cast-iron block is firmly fixed by slips of wood and wedges. Into this block are fitted three brass bushes, which form the upper bearing of the mill-spindle. These are adjusted by means of wedges, the screwed tails of which pass downwards through a cast-iron ring, and are regulated by thumb-screws on each side of it. Small semicircular chambers are formed in the socket between each bush, and filled with hemp and tallow, for the lubrication of the mill-spindle; and the whole is carefully protected from dust by slips of sheet iron screwed over it.

The Millstones.—The diameter of the millstones most in use at the present day is 4 ft., and their thickness about 12 in.; one-half of this thickness is composed of French burr, a very hard, though porous mineral, of a silicious nature; the other half is made up of plaster of Paris. In consequence of the difficulty of obtaining sufficiently large masses of the French stone, it is usual to construct the millstones in segments, which are cemented together, and the whole firmly bound by iron hoops passing round the circumference. The lower stone is, in the first instance, carefully dressed into a perfectly flat, plane surface, but the upper one is made slightly hollow for a small distance from the central aperture, so as to allow the grain to be freely admitted between the stones. Being thus prepared, grooves are then cut on the rubbing surfaces of both, in the manner indicated in Fig. 5969.

The number of channels formed in the stones, and consequently the number of compartments, or quarters into which they are primarily divided, are varied by different millers, but the mode of drawing the lines as here given is applicable in all cases. The circumference of the stone is first divided into equal parts; lines are drawn from each division to the centre; these radii determine the limits of the grooves in each compartment. A chord is then drawn, joining the bounding radii of any two compartments; this chord is, of course, bisected by the intermediate radius. These are the outlines of the grooves, which are then to be cut into the stone, perpendicularly on one side and obliquely on the other, so that each furrow shall have a sharp edge. The direction of the grooves being the same in both upper and lower stones, as they lie on their backs in the position proper for being cut, it is obvious that when the former is reversed and set in motion, their sharp edges will meet each other after the manner of a pair of scissors, and thus grind the corn more effectually when it is subjected to the action of the unbroken surfaces between the channels.

Adjustment of the Lower Stone.—It is of the most essential importance to the proper working of any pair of stones, that the grinding surface of the lower stone should be perfectly level, and that its centre should be exactly perpendicular above that of the lower bearing of the mill-spindle. To secure the former of these conditions, three pinching screws are fitted into the cone, that number being greatly preferable to four in adjusting the level of any surfaces, and, bearing against small slips of iron sunk into the stone, it can be raised or depressed by them to any required extent. The centering of the stone is effected by means of four pinching screws acting horizontally upon it. To secure it against deviating from the truth after having been properly adjusted, all these screws are provided with jam-nuts.

Adjustment of the Mill-spindle.—The lower bearing or footstep of the spindle is also made capable of nice adjustment, both horizontally and vertically. The former is necessary in order to ensure the accurate working of the driving wheel and pinion, and the latter to regulate the pressure of the upper upon the lower stone, and to compensate for the changes produced upon both by the frequent dressings which their grinding surfaces have to undergo.

The footstep, which is of gun-metal, is turned and fitted accurately into a cast-iron socket, resting on the upper diaphragm of the standard; the hole into which it is inserted, and the annular recess by which it is surrounded, being made of somewhat greater diameter than the corresponding parts of the socket itself. Its exact position is determined and secured by the four radial pinching screws passing through the ring, and working in nuts fitted into recesses cast upon its interior surface.

The Feeding Apparatus.—The supply of grain admitted between the stones is regulated by means of a cast-iron pipe, open at both ends, the lower end being brought into close proximity with the rhind, while the upper part encloses the pipe in which the feeding hopper terminates. It is suspended by means of a cast-iron lever. A small chain attached to the end of the lever, and passing over a friction-pulley at the bottom of the stone case, serves to connect this feeding apparatus with an ingenious little piece of mechanism attached to the standard, by which the miller is enabled to regulate the supply with the greatest nicety.

The Disengaging Apparatus.—The driving pinion is fitted upon the mill-spindle so as to be capable of sliding up and down upon a sunk feather. When fully in gear with the wheel, it rests upon a collar formed on the upper surface of a large brass nut, by which the miller is enabled to keep the pinion invariably in its proper position with regard to the wheel, independently of the position of the spindle, which requires to be slightly lowered every time the stones are dressed. When properly adjusted the pinion is secured to the spindle by a tapered key

It is, however, necessary to throw each pair of stones periodically out of gear with the general range, to admit of their being dressed. For this purpose the tapered key is removed, and the pinion raised out of contact with the teeth of its driving wheel by means of a species of small jack or lifting apparatus attached to the standard.

The Elevators and Creepers.—The material employed is cast iron; the creeper is made in 6 ft. lengths, each length being in the form of a tube, $3\frac{1}{4}$ in. diameter, and about $\frac{3}{8}$ in. thick, with broad leaves or threads cast round it after the manner of an Archimedian screw. The thickness of the threads does not exceed $\frac{3}{16}$ in. at the outer extremity.

The different lengths of which the entire creeper is composed are joined together by short wrought-iron studs, forming also the journals on which it revolves. These are made with square tails fitted into similar holes formed in the centre of small cylindrical blocks, which are carefully turned on their exterior surfaces and driven into the open ends of pipes previously bored to the same diameter. This construction at once ensures a strict rectilinear axis for the entire range, whatever may be its length.

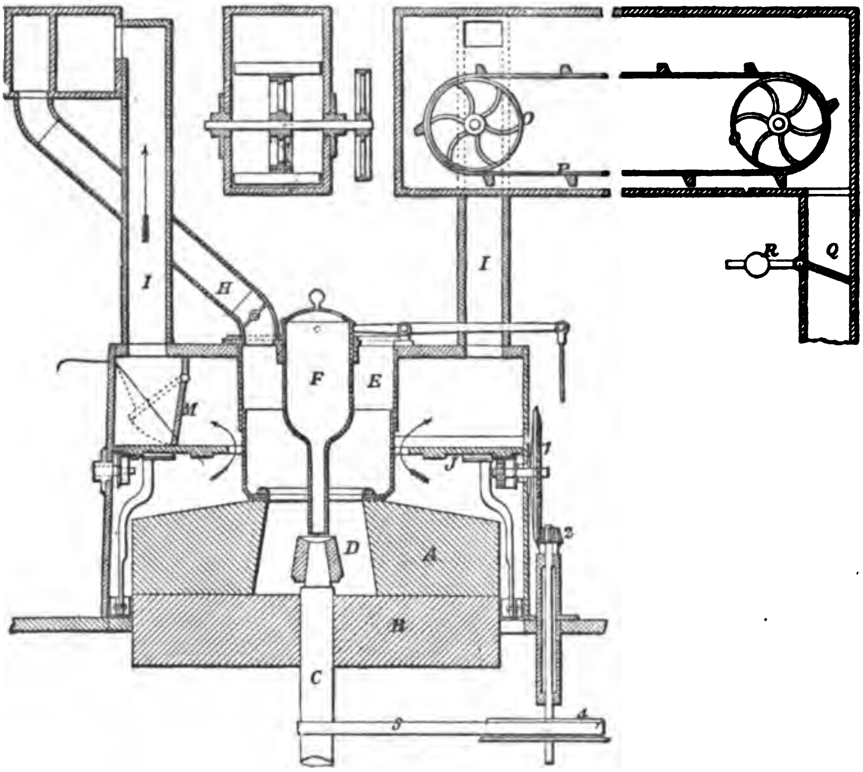
The following is a list of wheels and speeds for the mill, Figs. 5938 to 5942;—

			ft.	in.					ft.	in.			
Fly-wheel,			13	10	diameter	= 40	revs.	into	7	0	= 79	revs. of	horizontal shaft
Bevel	„	A	3	6	„	= 79		„	1	$10\frac{1}{2}$	= 145	„	millstones and upright.
„	„	B	3	0	„	= 145		„	1	9	= 250	„	cross-shaft to dressing machines.
„	„	C	1	$2\frac{3}{8}$	„	= 250		„	2	1	= 144	„	longitudinal shaft for screen creepers and fan.
„	„	D	1	$1\frac{1}{8}$	„	= 145		„	1	$11\frac{1}{8}$	= 83·6	„	cross-shaft in No. 5 room.
Mitre	„	E	1	8	„	= 83 6		„	1	8	= 83·6	„	longitudinal shaft for hoists and creepers.
Pulleys		F	2	6 × 9	„	= 250	revs.	on to	1	3	= 500	„	dressing machines.
„		G	2	6 × 9	„	= 144		„	1	3	= 288	„	screen.
„		H	2	6 × $6\frac{1}{4}$	„	= 144		„	0	7	= 617	„	fan under screen.
„		I	1	2 × 6	„	= 144		„	2	$2\frac{1}{4}$	= 78	„	creepers over bins.

	ft.	in.				ft.	in.			
Pulleys K	1	6 × 4½	diameter =	79	revs. on to	1	6	=	79	revs. of creepers on ground floor.
„ L	2	0 × 6	„ =	83·6	„	2	6	=	66	„ chain barrel 8 in. diam.
„ M	1	7 × 6	„ =	83·6	„	1	8	=	78	„ creepers for screen.
„	1	2 × 6	„ =	83·6	„	2	3½	=	42	„ meal elevator—not shown.

Figs. 5943 to 5947 are of Smith, Wood, and Don's plan of hanging millstones. Fig. 5943 represents a pair of millstones in section. A is the ripper or running millstone; B the bed-stone; C the

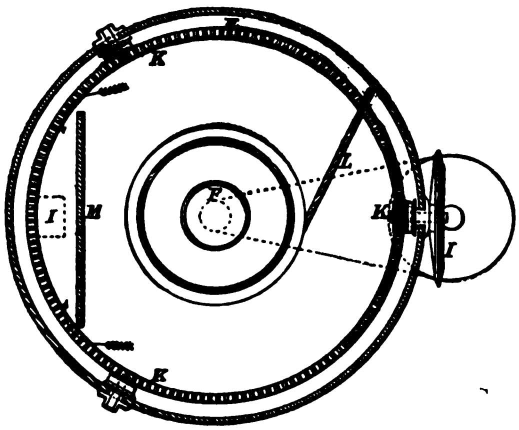
5943.



stone spindle, on the top of which is fixed the balance or universal rhind D carrying the running stone; E is the eye-box, the upper part of which is attached to the top of the millstone case, and the lower part slides within the upper part, and has a circular valve at the under side, which lays on a ring fitted to the eye of the running stone, thus causing the current of air when either blown into or driven through the eye of the stone to pass between the grinding surface of the millstones; F is the hopper receiving the grain to be ground, and delivering the same to the saucer fitted to top of stone spindle, which distributes it equally between the surface of the millstones regulated by the lever G. The feed-hopper F is fitted to, and slides in, a circular opening on the top plate of the eye-box E. H is the blast-pipe for conducting the air blown into the eye of the millstone; I is the exhaust-pipe to take off the stive or damp air or plenum of air blown into the stone cases used in Bovill's system of grinding; J is a revolving table borne on three or more rollers K fixed to the inside of the stone case. A circular rack-wheel, Fig. 5944, is fixed to the under side of this revolving table. A pinion, forming one of the rollers, works into this circular rack-wheel; this pinion being caused to revolve by bevel-gearing 1, 2, being set in motion by a strap 3 from the stone spindle driving the pulley 4, on the spindle of which the bevel-pinion is fixed. This circular or revolving table has an annular opening around the eye-box E, which allows the stive and moist air to escape from the runner-stone into the upper part of the stone case, where the stive or fine flour is deposited on to the top of the revolving table, and the moist air is drawn away by the exhaust up the spout I, which stive is swept off the revolving table by the sweeper L, Fig. 5944, which sweeps the stive or fine flour down the annular space on to the top of the runner-stone, from whence it is delivered down the meal-spout with the meal or ground flour. M is a baffling board hung to the under side of top of stone case, which may be opened, more or less, as required, by pulling the string; this is to check the too rapid current of the air and stive up the exhaust-spout I, and cause the depositing of the stive or fine flour on the top of the revolving table. N, N, Fig. 5945, are two or more perpendicular bars of iron fixed to under side of revolving table and revolving with it. To the lower end of these bars is attached a leather strap *a*, having angle-iron plates *b* fixed to the side of the

strap next to the bed-stone, and leather projections or sweepers *c*, fitted to the side next to the inside of the case; so that, when the revolving table is set in motion, it scrapes all the meal deposited in

5944.



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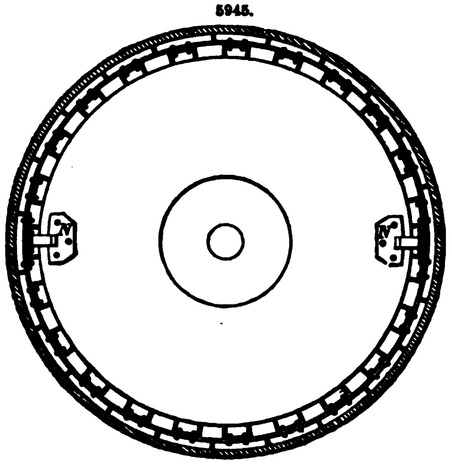
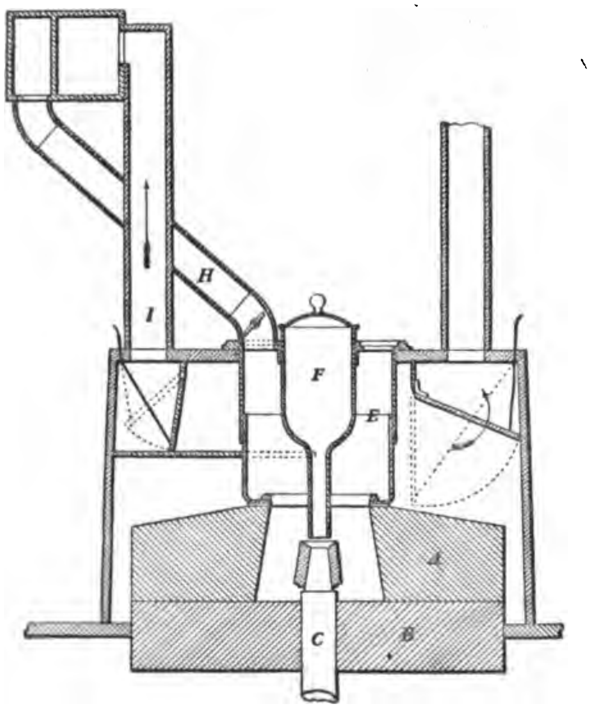
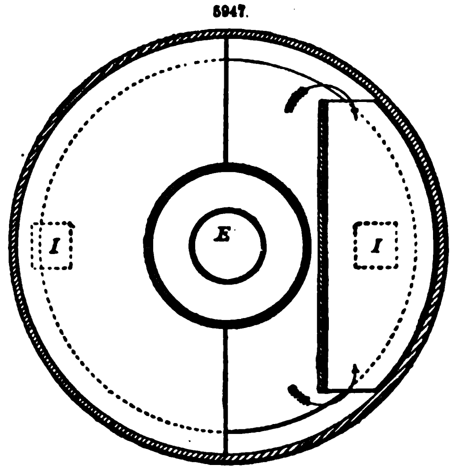


5946.



5947.



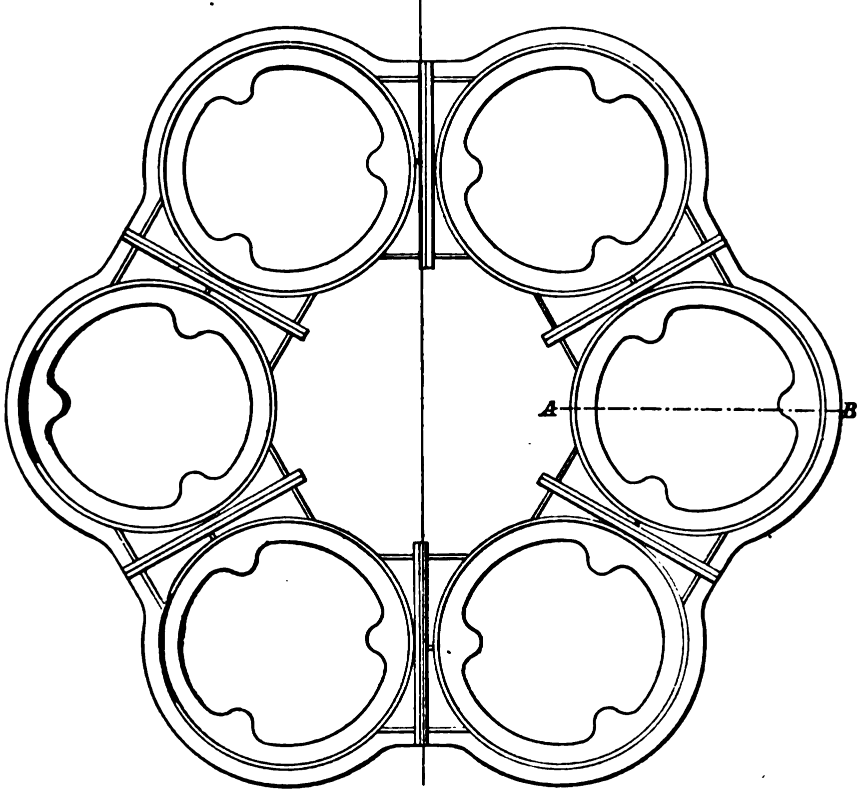
the space between the bed-stone and stone case, delivering the same to the meal-spout, thus assisting to keep the stones cool, and preventing the accumulation and waste of meal in the stone case.

Figs. 5946, 5947, are intended to show the method adopted of using a fixed table for catching and depositing the stive on a fixed table instead of a revolving table.

To save expense and economize space a set of stones may be arranged as in Figs. 5948 to 5950, which show the bed-plates of six pairs of stones supported by six columns.

Fig. 5951 is an end view, Fig. 5952 a longitudinal section, Fig. 5953 a plan of the granary; and Fig. 5954 a plan of the stone floor of a small steam corn-mill. There are here two pairs of stones driven through bevel-gearing by an ordinary stationary engine *g*, which also furnishes the power for working the cleaning, feeding, and dressing apparatus. In the ordinary course the grain is passed from the bin *m* to the smut machine *j*, where it falls upon an iron plate which is fixed upon and revolves with a central shaft at a velocity of about 550 ft. a minute, and round this

5948.



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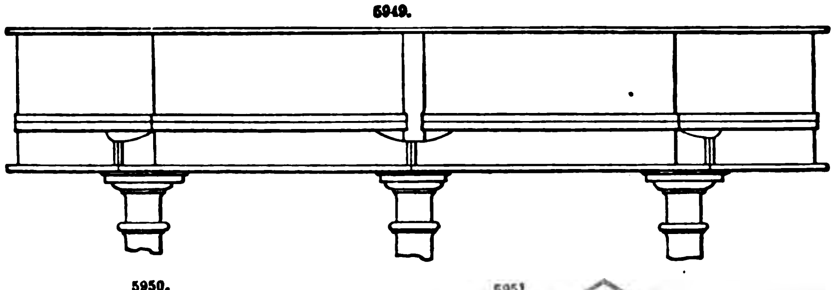

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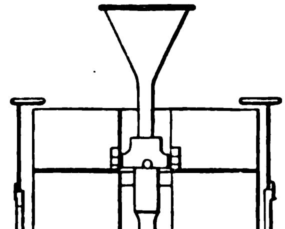
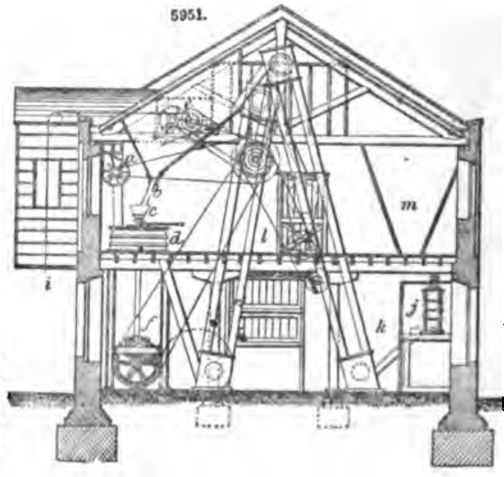


Section through A.B with Stones &c.

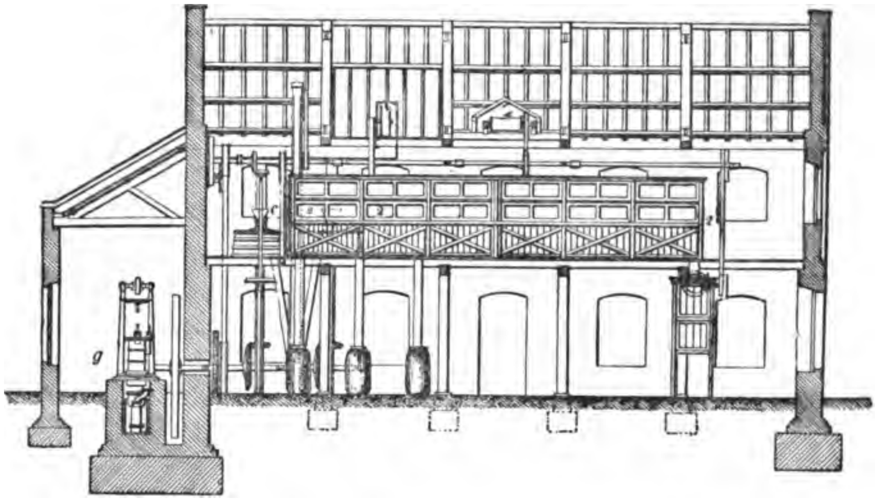
5951.



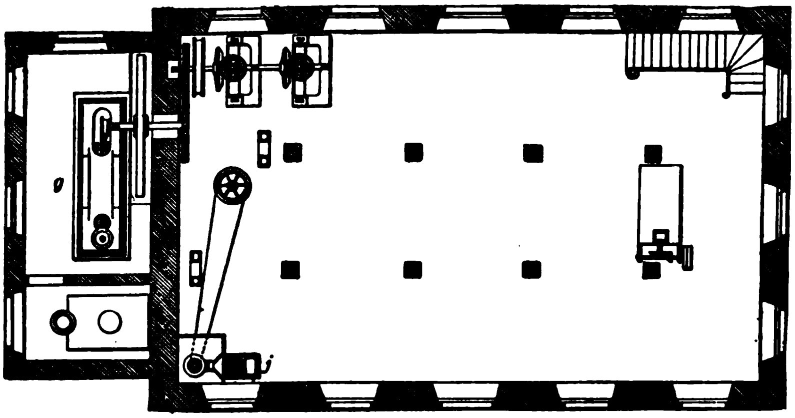
Reference to Figs. 5951, 5952;—*a*, exhaust-fan from stone; *b*, feeding pipe; *c*, stone hopper; *d*, stone case; *e*, grain-fan; *f*, driving gear; *g*, steam-engine; *k*, grain-elevator; *l*, flour-elevator; *m*, corn-bin; 2, dressing machines; *z*, *i*, sack-tackle.

shaft are attached radially a number of vertical beaters. In passing these beaters the corn, whilst running from one extremity to the other of the machine, has a large portion of dust and foreign

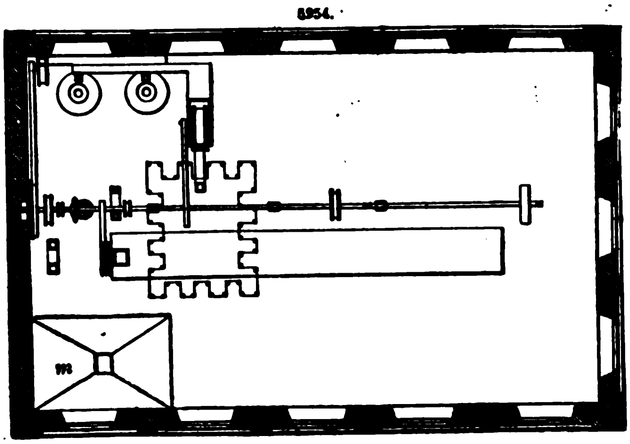
5952.



5953.



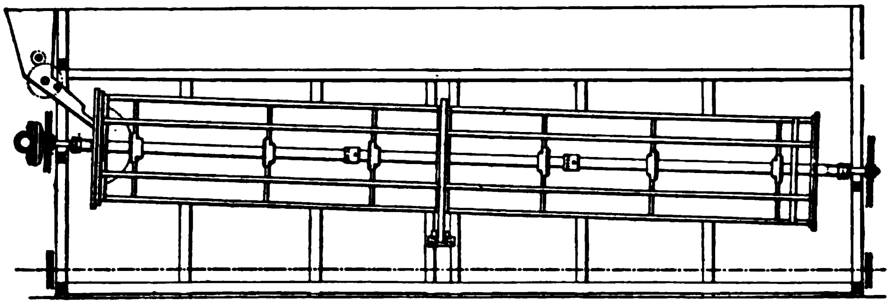
5954.



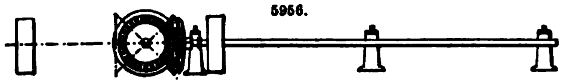
matter removed from it. The smut machine is covered with wire gauze, and is usually enclosed in a room by itself. From the smut machine the wheat is passed over a wheat screen, and is then taken up by an elevator to the feeding bin *e*, being submitted whilst leaving the spout from the elevator to a fan-blast, which clears it of impurities lighter than itself. It is then passed through the stones, ground, elevated, and dressed in the usual way.

Figs. 5955 to 5957 serve to illustrate the construction and working of the silk bolting machine, called also dressing-machine or silk. The cylinders are from 20 to 30 ft. in length, 3 to 3½ ft. diameter, and make from twenty to twenty-five revolutions a minute. At distances of 3½ to 4 ft. radiating rods are inserted on the hollow shaft, and these form the rods

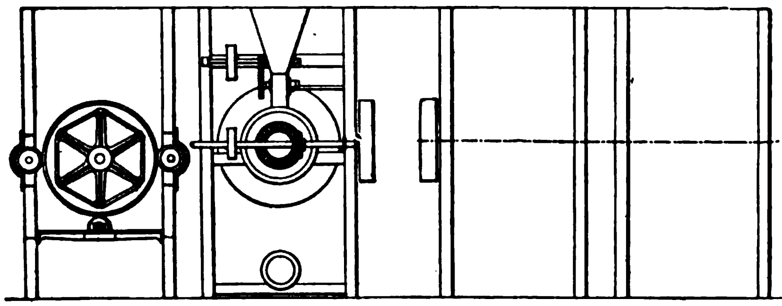
5955



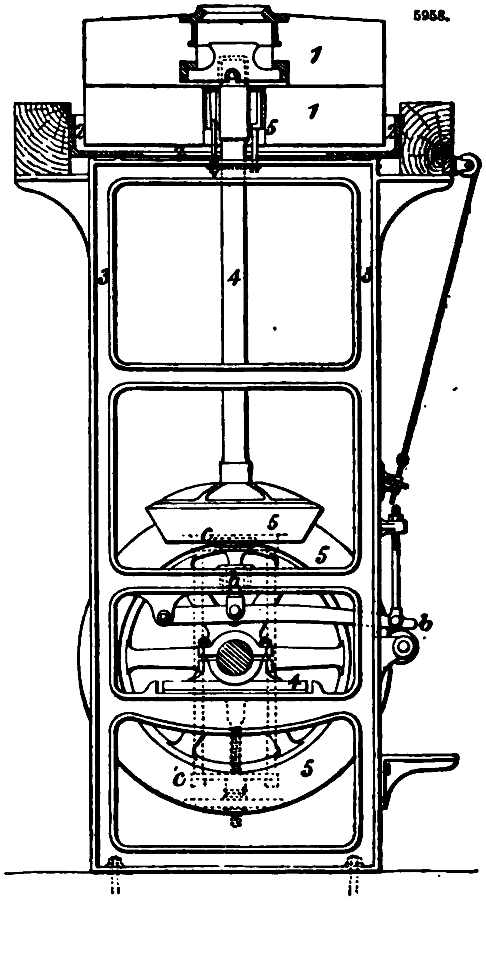
5956.



5957.



5958.

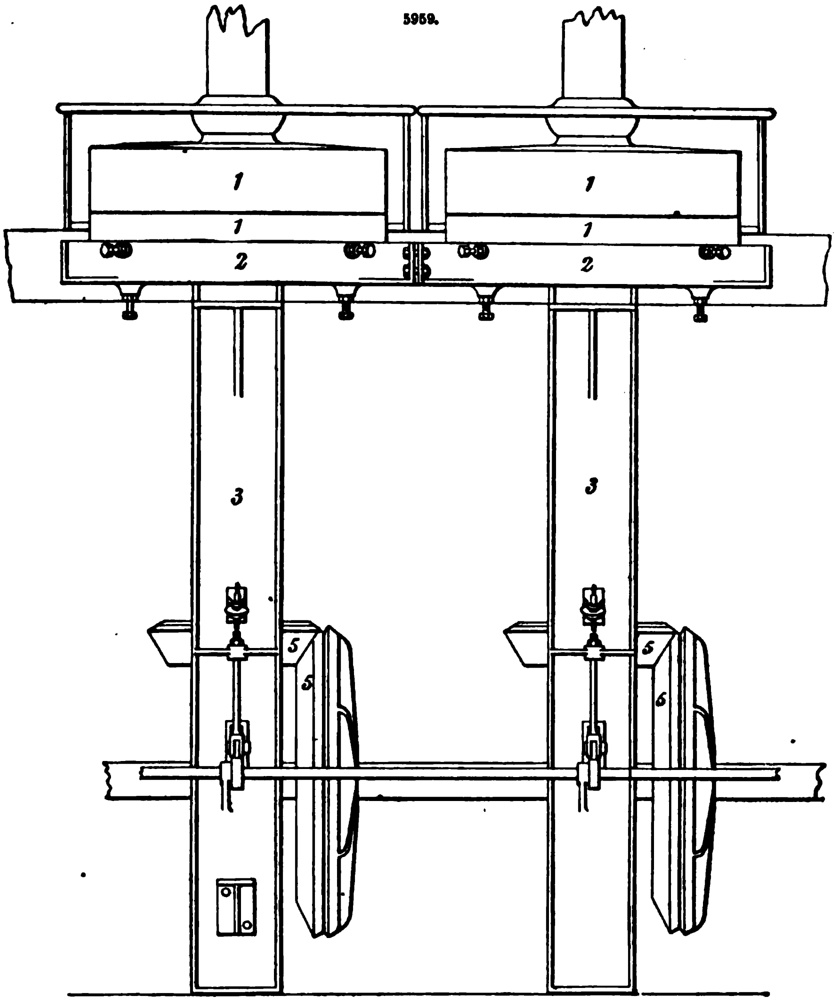


of the machine to which the silk covering for the flour to pass through is attached. The shaft ends in pivots, which have their bearings in plummer-blocks bolted to a cross-piece of iron. The machine is driven by a cross-shaft having two bevel-wheels keyed upon it, which gear into corresponding wheels on the driving shafts of the cylinders. The cross shaft also gives motion, through the intervention of a strap, to a pulley on the shaft of the creeper, shown by the dotted line in Fig 5955, which carries the flour along the trough under the reel.

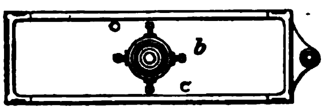
Figs 5958, 5959, are a modern plan of setting millstones designed for this mill by Thomas Don; 1, 1, are millstones 4 ft. 2 in. diameter, and worked at a speed of 125 revolutions a minute; the lower stone lays upon the stone plate 2, 2, supported by upright frames 3, 3; 4, stone spindle driven by the bevel-gearing 5, 5. Fig. 5960, the cross-piece of the frame carrying the stone spindle step; *b*, lightering iron for lifting the stones, and so regulating the quality of the meal ground. Fig. 5961, cross-plate with space for plummer-block carrying horizontal driving shaft. Fig. 5962, stone spindle bush bar, fixed into centre of bed-stone. Fig. 5963, bearings let into eye of top stone for centres of balance-pin to work in. Fig. 5964, plan showing the manner of connecting the bed-stone plate. Fig 5965, details of arrangement *c*, *c*, for lifting bevel-pinion 5 out of gear.

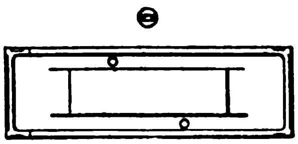
The meal travels from the elevator along a creeper, and enters the dressing machine by a hopper; here it makes a progressive onward motion, rising and falling by gravi-

5959.



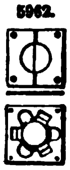
5960.



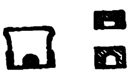


5961.

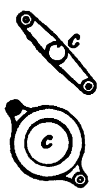
5962.



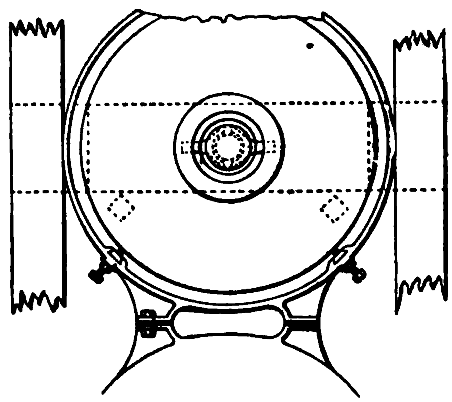
5963.



5965.



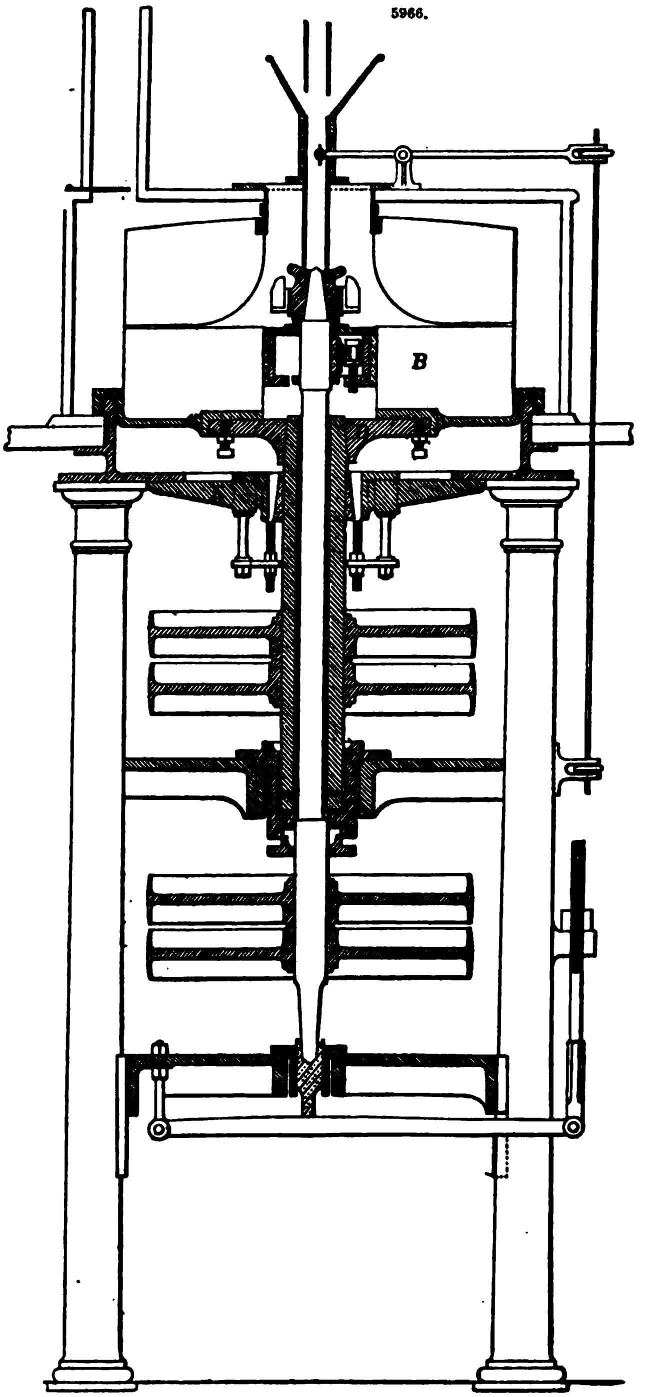
5964.



tation from the sides of the reel till the flour has passed through the interstices of the silk and the bran is delivered at the end of the machine.

Fig. 5966 is a vertical section of a pair of millstones as arranged by Wm. Cullen. The stones are placed in the ordinary horizontal position, but arranged to be driven in opposite directions. Fig. 5967 is a plan of a bed-plate E set upon the supporting pillars, and furnished with an adjustable upper bearing for a vertical tubular shaft which carries the lower stone B. Fig. 5968 is an inverted plan of a dish-plate C which is set on a cross-head or rhind D fixed in the upper end of the tubular shaft, and which is formed with a turned flange to cover a raised flange formed on the bed-plate, and so prevent the meal from getting under the stones. The lower stone is fixed in this dish-plate, and can be accurately levelled and adjusted by means of screws passing through the arms of the cross-head. Fig. 5969 is a face view of the lower stone B, and shows the details of an upper adjustable bearing for the central shaft which passes through the tubular shaft, and carries the upper stone by means of the usual rhind, shown inverted in Fig. 5971. The central shaft is supported on a footstep bearing in a transverse frame-piece fixed to the pillars, this bearing being adjustable by means of a lever and screw. The bearing for the upper end of this central shaft is fitted in the eye of the lower stone B, and consists of a box containing three equidistant brass bearing pieces G, which are adjustable radially by wedges acted on by screws. The spaces between the brass pieces are filled with fibrous material, which is saturated with oil, and the whole is covered with a plate to prevent dust from getting to the bearing surfaces. This arrangement of bearing admits of the central shaft being accurately centred with reference to the lower stone, and of its running with perfect steadiness, points requiring the greater attention when both stones revolve.

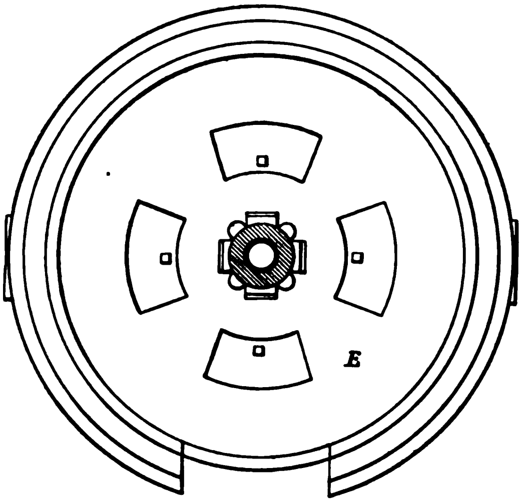
5966.



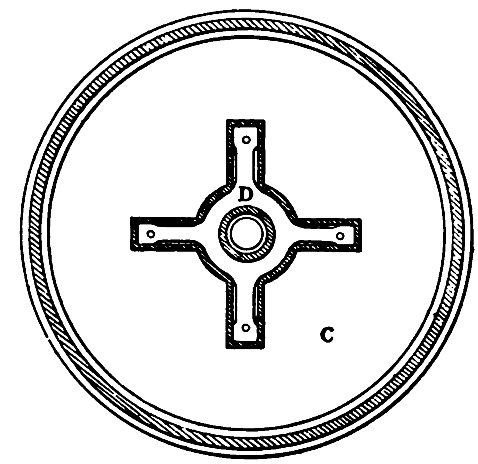
The proper supporting and steadying of the tubular shaft carrying the lower stone is also of great importance; and the bearing at its upper end consists of four brass pieces held in spaces, formed in the plate and made

adjustable radially by wedges and screws, whilst spaces between the brass pieces are filled with fibrous material saturated with oil. A brass cylinder surrounds the lower part of the tubular

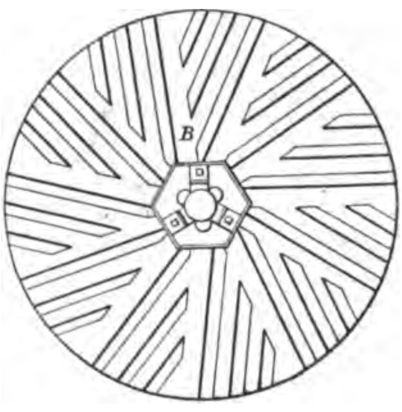
5967.



5968.



5969.



5970.

shaft, and the bottom of the shaft rests on three flat rings, the top and bottom rings being brass and the middle one cast iron, whilst all these are quite loose and free to revolve, and vertical grooves are formed down the inside of the brass cylinder, and radial grooves are formed on the side faces of the rings, so that the oil has free access to every part.

With this arrangement of the foot-step bearing, if any extra friction should take place between the bottom of the tubular shaft and the ring next to it, some of the rings will revolve, but the continuous lubrication will in a few seconds cause the shaft-foot to glide over its former resistance and again revolve on the surface of the top ring. A stuffing-box gland is applied beneath the footstep bearing of the tubular shaft, to prevent the oil from dripping through and down upon the parts beneath.

The details of the bearing are carried in a box which is adjustable in a transverse frame-piece fixed to the pillars.

Each of the shafts has in it a pair of pulleys, one of each being fast, the other loose, and the shafts may be driven in opposite directions from a single parallel shaft by means of a pair of belts, one of which is open, the other crossed.

See Agricultural Instruments. Barn Machinery. Belting. Construction. Cotton Machinery. Flax Machinery. Gearing. Gunpowder. Paper Machinery. Sugar Machinery.

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MOLECULE. Fr., *Molécule*; Ger., *Molecül*; Ital., *Molecula*; Span., *Molécula*.

All matter consists of an aggregation of minute particles. These particles are called *molecules*, and they differ from atoms in being always a portion of some aggregate. Molecules are of two kinds, called respectively *integrant* and *constituent*. Integrant molecules are the smallest particles into which a simple body can be conceived to be divided, or the smallest particles into which a compound body can be conceived to be divided without being resolved into its elements. Constituent molecules are the molecules of each element which forms an integrant molecule of a

compound. Thus an integrant molecule of water is composed of constituent molecules of oxygen and hydrogen. It is with the latter kind we have chiefly to deal in chemical investigations.

The distinction between an atom and a molecule must be clearly recognized. Hofmann, in his Modern Chemistry, gives the following definition, which is now generally accepted. "We may," he says, "define an *atom* of an elementary body to be the smallest proportional weight thereof that is capable of existing in *chemical combination*, and we may define the *molecule* of an elementary body to be the smallest proportional weight thereof that is capable of existing in the *free or uncombined state*." Thus a molecule, or as it is often called, an *elementary molecule*, may consist either of an isolated atom, or of a group of atoms.

The bulk, or *molecular volume* of an element in the gaseous state, is the same as the molecular volume of hydrogen at the same temperature and pressure, and in numerous cases the *molecular weight* of an element is twice its atomic weight. The following list of the elements whose molecular volumes have, up to the present time, been determined, is given by Dr. Frankland. The molecules of mercury, cadmium, and zinc contain one atom, and are termed *monatomic* molecules; those of hydrogen, oxygen, chlorine, bromine, iodine, fluorine, nitrogen, sulphur, and selenium contain two atoms, and are termed *diatomic* molecules; the molecules of oxygen, as ozone, contain three atoms, and are therefore *triatomic;* those of phosphorus and arsenic contain four atoms, or are *tetratomic*, and those of sulphur, under certain conditions, are *hexatomic*. Thus it will be seen that an element, as in the case of oxygen and sulphur, may, under different conditions, have two distinct molecular weights. We shall now enter more fully into the subject of molecular weight.

In a gaseous state, all bodies, whether simple or compound, have sensibly the same coefficient of dilation, that is, they increase sensibly by an equal fraction of their volume for an equal increase of temperature. All are equally compressed under the same conditions, that is, they are reduced to the same fraction of their volume for the same increase of pressure, other things being equal. The elastic force of gases is therefore nearly the same for all; and as it is generally admitted that the gaseous molecules are in motion, and that the elastic force of gases is due to the shock of their molecules against the walls of the vessels wherein they are contained, the most simple way of explaining that they all possess the same elastic force, under the same conditions, is to admit that equal volumes of gases, under the same pressure and temperature, contain the same number of molecules.

This supposition rests upon Gay-Lussac's law relative to the combinations of gaseous substances. If gaseous bodies are formed of molecules, if the decompositions and the combinations result from the exchange of atoms that takes place among the molecules, or from the union of several of these molecules into one, it is evident that the number of the molecules which have reacted, and the number of those which result from the reaction, must present a simple ratio. For the reactions can take place only between one molecule and another molecule, or between one molecule and two molecules, and so on. Therefore, if in equal volumes and under the same conditions of pressure and temperature, all gases contain the same number of molecules, the simple ratio which must exist between the number of reacting molecules and that of the molecules formed in the reaction, ought equally to exist between the volumes of the gases, before and after the reaction; and such is actually the case.

The hypothesis that, in equal volumes, all gases contain the same number of molecules, was first propounded by Avogadro, but was more fully developed by Ampère, under whose name it is better known. Starting from this principle, let us compare equal volumes of chlorine and hydrogen. We shall find in this case that the volume of chlorine weighs 35½ times more than that of the hydrogen, and hence we infer that the molecule of chlorine weighs 35½ times more than the molecule of hydrogen. But, as we have already seen when treating of atomic weight, the molecule of hydrogen is composed of two atoms. Consequently the atom of hydrogen is equal in weight to only one-half of its molecule. As therefore a molecule of chlorine weighs 35½ times as much as a molecule of hydrogen, it will weigh 71 times as much as an atom of the same body. If then we take the weight of the atom of hydrogen as the unit for molecular weight, as it has been taken for atomic weight, we shall have 71 as the molecular weight of chlorine. Thus the molecular weight of a simple or compound substance is found by taking its density of vapour relatively to hydrogen, and multiplying by 2 the ratio obtained.

As the densities of vapour are usually taken relatively to air, and as air weighs 14·435 times more than hydrogen, the density relative to air must be multiplied by that number to bring it relative to hydrogen. Moreover, as this latter density must be doubled in order to obtain the molecular weight of a substance, we may shorten the operation by multiplying at once the density relative to air by twice 14·435, or 28·87. Therefore, to find the molecular weight of a body, multiply its density of vapour taken relatively to air by 28·87. If all bodies were volatile, nothing could be easier than to determine their molecular weight. Such, however, is not the case. A large number of compound bodies are destroyed before reaching the temperature at which they would be reduced to vapour. Hence another means of obtaining their molecular weight is required.

Either bodies are capable of entering into combination with other bodies, or they are not. Let us take the former case with an example.

Stearic acid is a fatty acid not sensibly volatile, in which a certain weight of potassium is capable of substituting itself for an equivalent weight of hydrogen. It has the closest possible analogy in properties with acetic acid, in which a substitution of potassium may likewise take place for a portion of its hydrogen, and of which the molecular weight has been determined, this substance being volatile. Experiments have proved that the molecular weight of acetic acid is 60, and that in 60 parts of this acid one of hydrogen may be replaced by 39 of potassium. If we seek the quantity of stearic acid capable of combining with 39 parts of potassium while losing one of hydrogen, we shall find this quantity to be 284. Hence 284 parts of stearic acid are equivalent to 60 parts of acetic acid, and as 60 of acetic acid represent the weight of the molecule of this acid, 284 must represent the weight of the molecule of stearic acid.

Exact results can be obtained from this method only on the condition that the bodies compared have the same molecular constitution. Thus an acid like acetic acid cannot be compared with citric acid, or at least it would be necessary to introduce into the comparison considerations of another order. Provided this condition be fulfilled, the molecular weight of a non-volatile substance capable of entering into combination with other substances may be found by determining what quantity of the substance is equivalent to the known molecular weight of a volatile matter having the same constitution. This quantity represents the weight of its molecule.

When the non-volatile substance is not capable of entering into combination, it must be subjected to the action of reagents, which destroy it. By this means new compounds are obtained, the molecular weight of which may be determined by one of the preceding methods. To find from the molecular weight of these latter, that of the primitive body, a number is chosen, which will enable the reaction to be expressed in the simplest manner, and this number is taken as its molecular weight. The results given by this method are not so trustworthy as those obtained by the preceding, to which recourse should always be had when possible.

If we take as the unit of gaseous volume, the volume of the quantity of hydrogen, the weight of which corresponds to our unit of weight, it is evident, from what has been said above, that the weight of the same volume of any simple or compound substance, considered in the gaseous state, will represent its density of vapour relative to hydrogen, and consequently the half of its molecular weight. Therefore, to find the molecular weight of a substance, multiply by 2 the weight of one volume of its vapour; or, which is the same thing, the molecular weight of a body will be equal to the weight of two volumes of its vapour. This fact is expressed by saying that all bodies have a molecular weight corresponding to two volumes of vapour.

It is evident that if half the above volume were taken as the unit of gaseous volume, the molecular weights of all bodies would correspond to four volumes of vapour. The greater number of modern chemists accept, for the sake of uniformity, the number 2; but old writers employed the number 4, a practice still persisted in by some.

Formerly the methods of determining the molecular weights were not based upon Ampère's hypothesis. Many of these weights were imperfectly known, and in treatises on chemistry only half their real value was assigned to them. Thus there were bodies whose molecular weight corresponded to two volumes, and others whose weight corresponded to four volumes. To Gerhardt is due the honour of enforcing the observance of Ampère's hypothesis, by showing that all molecular weights must correspond to one and the same gaseous volume, 2 or 4, according to the unit adopted.

There are, however, some compound substances, such as hydrated sulphuric acid and hydrochlorate of ammonia, that appear to form exceptions to this law. The molecular weight of these substances can in nowise be doubled, without at the same time doubling the atomic weights of the simple bodies which constitute them, and these atomic weights are too surely established to allow of their being modified. Yet the density of vapour of these compounds is such that their molecular weight corresponds to 4 or 8, and not to 2 or 4 volumes of vapour.

To explain this anomaly, many chemists have supposed that in these cases dissociation takes place; in other words, they have supposed that, under the influence of heat, those bodies which present anomalous densities of vapour are decomposed into two others, each occupying the volume which the primitive body would occupy alone, if it were not dissociated, that is, 2 volumes. The two bodies together therefore, according to this hypothesis, occupy double the volume we should justly expect, if the compound whose density of vapour is being determined did not become decomposed; and if the two bodies which are separate when heated are capable of uniting again when cooled, the operator does not perceive the action, and thinks, consequently, he has found an anomalous density. To explain this matter more clearly, we will take an example. Chloride of ammonia is a compound of chlorine, hydrogen, and nitrogen; and if a molecule of this substance be heated, it will be decomposed into a molecule of hydrochloric acid—a compound of chlorine and hydrogen—and a molecule of ammoniacal gas—a compound of hydrogen and nitrogen. As the number of molecules has been doubled, the volume occupied by the vapour should be doubled too. When this mixture of hydrochloric acid and ammoniacal gas becomes cool, these two substances will again enter into combination, and the two molecules will reunite into one. If this be the case, those bodies which present anomalous densities are simply bodies that are not volatilized without undergoing decomposition. And it may be remarked that the latest researches of able chemists seem to have established the hypothesis upon a sound basis.

But however exact in theory, it is none the less true in practice that errors may be committed by relying solely upon the densities of vapour to obtain the molecular weights. Whether it be due to dissociation or not, these densities may deceive us, and means are needed for verifying the molecular weights determined by them. There exists a compound of hydrogen and carbon, known as marsh gas. The density of this gaseous compound is such that the molecular weight deduced from it is equal to 16. But is this the exact molecular weight? Analysis shows that marsh gas contains $\frac{3}{4}$ of its weight of carbon and $\frac{1}{4}$ of hydrogen. If therefore its molecular weight is 16, this weight is formed of 12 parts of carbon, corresponding to one or more atoms of this substance—we say one or more because we are not supposing the atomic weight of carbon known—and 4 parts of hydrogen, which is equivalent to 4 atoms, since the atom of hydrogen weighs 1. The atom being indivisible by chemical agency, the smallest quantity of hydrogen which, in the compound in question, can be replaced by another body, is equal to 1, that is, to the quarter of the hydrogen contained in the substance. If therefore the molecular weight of marsh gas is really 16, we may substitute another simple body for the $\frac{1}{4}$, $\frac{2}{4}$. $\frac{3}{4}$, or $\frac{4}{4}$ of the hydrogen. But if the molecular weight were only 8, this gas would be composed of 6 parts of carbon and 2 of hydrogen, and, in that case, only the half of the whole of the latter element could be replaced by another, never the quarter. Again, if the molecular weight were 32, there would be 8 parts of hydrogen, and this metalloid might be replaced by eighths. Now in marsh gas the hydrogen is replaceable by quarters, and by quarters only. Therefore the molecular weight deduced from its density is the true one. In

the greater number of cases the densities of vapour give the exact molecular weight; but as there are a few exceptions, it will always be necessary to verify the results deduced by the system of substitution. See ATOMIC WEIGHTS.

MOMENTUM. FR., *Moment d'une Force*; GER., *Moment einer Kraft*; ITAL., *Impulso*; SPAN., *Momento*.

Momentum is the quantity of motion in a moving body, being always proportioned to the quantity of matter multiplied into the velocity; it also means impetus.

MORTISE. FR., *Assembler à tenon et mortaise*; GER., *Verzapfen*; ITAL., *Immorsare*; SPAN., *Mortaja*.

See JOINTS.

MOULDING. FR., *Moulage*; GER., *Formerei*; ITAL., *Imposta*; SPAN., *Moldura*.

A moulding, or molding, is anything cast in a mould, or which appears to be so, as grooved or ornamental bars of wood or metal. Architecturally, a moulding is a projection beyond the wall, column, wainscot, and so on. An assemblage of mouldings forming a cornice, a door-case, or other decoration.

MUFFLE. FR., *Moufle*; GER., *Muffel*; SPAN., *Mufla*.

See ASSAYING. FURNACE.

NEUTRAL AXIS. FR., *Axe neutre*; GER., *Neutrale Achse*, ITAL., *Asse neutro*; SPAN., *Eje neutro*.

See MATERIALS OF CONSTRUCTION, p. 2338.

NICKEL. FR., *Nickel*; GER., *Nickel*; ITAL., *Níckel*; SPAN., *Níquel*.

Nickel is a greyish-white metal, resembling silver in appearance, and capable of receiving a high polish. It is of about the same hardness as iron, and, like that metal, it is malleable and ductile. In fusibility, it is about equal to manganese, and, after it has been subjected to the process of hammering, its specific gravity is 8·66. Its atomic weight is 59. Molecular weight, unknown. It is strongly magnetic at ordinary temperatures, but loses this property when heated up to 660° Fahr.; and it is so little oxidizable that it may be exposed for a long time to a moist atmosphere without undergoing change. Dilute hydrochloric and sulphuric acid dissolves it with a development of hydrogen gas, and nitric acid oxidizes it very readily. Carbon forms with nickel a compound more fusible than the pure metal, and analogous in this respect to cast iron. Only one combination of this metal with each of the halogen metalloids is known; this combination corresponds to the formula $Ni\,R^2$.

Nickel occurs in a native state only in meteoric stones, in which it is always present in association with iron. It is found in considerable abundance in certain parts of Germany, Hungary, and Sweden, where it occurs in the form of *Kupfernickel*, so called from its colour, being a combination of nickel and arsenic. The metal is obtained on a large scale, for the purpose of making German silver and other alloys, chiefly from this compound. It may be obtained in small quantities by reducing one of its oxides by means of hydrogen at a high temperature, or by exposing the oxalate to a very high temperature in a crucible lined with charcoal.

Oxygen combines with nickel in two proportions, forming thus the protoxide $Ni\,\Theta$ and the sesquioxide $Ni_2\,\Theta_3$. To the protoxide corresponds a hydrate $\left.\begin{matrix}Ni\\H_2\end{matrix}\right\}\Theta_2$.

The hydrogen of this hydrate is replaceable by acid radicals, and salts of nickel are formed which may be called minimum salts. The sesquioxide loses oxygen in the presence of the oxides, and is thus converted into minimum salts; when in contact with hydrochloric acid, it develops chlorine by giving protochloride. No salt of nickel is known corresponding to it. The single sulphate and the double sulphates generated by nickel are isomorphous, not only with the sulphates of cobalt, but also with the minimum sulphates of iron and manganese, and with those of the metals of the magnesian series.

The tetratomic character of nickel, like that of cobalt, is very difficult to establish. We have in this case only one compound on which to base this character, namely, the sesquioxide, an unstable substance, incapable of forming salts, which substance may be considered as resulting from the aggregation of several molecules of oxygen, and therefore proving nothing. On the other hand, nickel is closely allied to zinc, magnesium, &c. It would consequently appear more rational at first sight to class it among the diatomic metals. But there are sufficient reasons for placing cobalt with iron, and the extreme analogy between nickel and cobalt obliges us to place the former in the class of tetratomic metals, with the acknowledgment that if its real or absolute atomic character is equal to 4, its apparent or manifested character is always equal to 2.

Characteristics of the Salts of Nickel.—The following are the characteristics of the salts of nickel;—

1. They are of an emerald green colour.
2. The fixed alkalies produce in them an apple-green precipitate of hydrate of nickel.
3. Ammonia partially precipitates the very neutral salts of ammonia. But if these salts are acid, or contain an ammoniacal salt, ammonia will not precipitate them. When the precipitation takes place, the precipitate dissolves in an excess of the reagent, and the liquor assumes a blue colour.
4. Hydrosulphuric acid does not precipitate them; the alkaline sulphurets produce in them a black precipitate insoluble in acetic acid and in dilute hydrochloric acid.
5. Cyanide of potassium produces in them a precipitate soluble in an excess of the reagent. This precipitate is reproduced when the liquor is saturated by sulphuric acid. Nickel is by this property distinguishable from cobalt; for though, with the salts of the latter metal, cyanide of potassium forms a precipitate also soluble in an excess of the reagent, when once the precipitate is dissolved it cannot be reproduced by sulphuric acid.

NORIA. FR., *Noria*; GER., *Noria*, *Paternosterwerk*; ITAL., *Noria*; SPAN., *Noria*.

A large water-wheel turned by the action of a stream, and carrying at its circumference buckets by which water is raised and discharged into a trough at the top.

See MECHANICAL MOVEMENTS, Fig. 5792.

NUTS AND BOLTS. Fr., *Ecrou et boulon*, Ger., *Schraubenbolzen und Mutter;* Ital., *Chiavarda e Dado*, Span., *Tuercas y pernos.*

A nut is a small block of metal or wood containing a concave or female screw used for retaining a bolt; the nut is screwed upon the end of the bolt upon the latter being passed through the bodies to be held together. The following Tables furnish particulars as to the weight and dimensions of iron nuts and bolts;—

TABLE OF HEXAGON NUTS AND BOLT-HEADS.

Diameter of Bolt in inches.	Width of Nut over Angles.	Width of Nut over Sides.	Thickness of Head.	Thickness of Nut.	Diameter of Bolt in inches.	Width of Nut over Angles.	Width of Nut over Sides.	Thickness of Head.	Thickness of Nut.
1/4	7/16	3/8	1/4	1/4	1 1/4	2 1/8	1 7/8	1	1 1/4
5/16	5/8	9/16	5/16	5/16	1 3/8	2 3/8	2 1/16	1	1 3/8
3/8	5/8	9/16	5/16	3/8	1 1/2	2 5/8	2 1/4	1 1/8	1 1/2
7/16	3/4	3/4	7/16	7/16	1 5/8	2 7/8	2 1/2	1 1/4	1 5/8
1/2	7/8	3/4	7/16	1/2	1 3/4	3	2 5/8	1 3/8	1 3/4
9/16	1	7/8	1/2	9/16	1 7/8	3 1/4	2 13/16	1 1/2	1 7/8
5/8	1 1/8	1	1/2	5/8	2	3 1/2	3	1 5/8	2
3/4	1 3/8	1 3/16	5/8	3/4	2 1/4	3 7/8	3 3/8	1 3/4	2 1/4
7/8	1 1/2	1 5/16	3/4	7/8	2 1/2	4 3/8	3 3/4	2	2 1/2
1	1 3/4	1 1/2	7/8	1	2 3/4	4 3/4	4 1/8	2 1/4	2 3/4
1 1/8	1 7/8	1 5/8	7/8	1 1/8	3	5 1/4	4 9/16	2 1/2	3

WEIGHT OF NUTS AND BOLT-HEADS IN LBS.

Diameter of bolt in inches	1/4	3/8	1/2	5/8	3/4	7/8	1	1 1/4	1 1/2	1 3/4	2	2 1/2	3
Weight of hexagon nut and head ..	·017	·057	·128	·267	·43	·73	1·10	2·14	3·78	5·6	8·75	17	28 8
Weight of square nut and head	·021	·069	·164	·320	·55	·88	1·31	2·56	4·42	7·0	10 5	21	36·4

OBLIQUE ARCH. Fr., *Arc de côté;* Ger., *Der schiefe Bogen;* Ital., *Arco obliquo*, Span., *Arco oblícuo.*

Oblique arches have been briefly treated of under the general heading of Bridge, and the several systems were, in that place, described and discussed. But the subject was there considered from a theoretical rather than a practical point of view, the object being mainly to explain the nature of the lines employed, and to demonstrate the correctness of the methods by which these lines are obtained; and although some practical processes were necessarily introduced, no attempt was made to render the treatment other than purely mathematical. The present article, on the contrary, is intended to be wholly practical. It will treat of the design and construction of oblique bridges as actually made and carried out by the engineer and the contractor.

An oblique or, as it is commonly called, a *skew* bridge is one in which the passages over and under the arch intersect each other obliquely. In conducting a railway through a district in which there are many natural or artificial water-courses, or in making a canal through a country in which roads are frequent, such intersections often occur. Before the introduction of railways skew bridges were seldom erected, it being more usual to build the bridge at right angles, and to divert the course of the road or the stream to accommodate it. But in a railway, and sometimes in a canal, such a deviation from the straight line of direction is inadmissible, and it therefore becomes necessary to build the bridge obliquely. In such a case, the axis of the arch is oblique to the face, and the angle which the axis makes with a perpendicular to the face is called its *angle of obliquity.* The distance by which one abutment, or line of springing, extends beyond the other, and which is, of course, dependent upon the angle of obliquity, is termed the *distance of obliquity* A skew arch has a direct and an oblique span; the former, or span on the square, is the perpendicular distance between the abutments, the latter, or span on the skew, is the distance between the abutments parallel to the face of the arch. The former is less than the latter in the ratio of the cosine of the angle of obliquity to unity. It is the span on the skew which is equal to that of the corresponding rectangular arch.

Rectangular and oblique arches are identical in their main features, and hence the fundamental principles of construction will be common to both. But in the latter the details of construction differ considerably from those adopted for the former kind. This difference is chiefly due to the altered position and form of the joints. The bed-joints in an arch should be perpendicular to the thrust along the arch, and to determine this position in the skew arch is a matter of some difficulty. If we draw upon the soffit of an arch of this kind, a series of parallel curves made by the intersections of the soffit with vertical planes parallel to the face, the best form for the bed-joints will be a series of curves drawn upon the soffit, and cutting the first series everywhere at right angles. But as these joints would be difficult of execution, spirals are in practice used as an approximation. The beds of the arch stones in a skew arch are consequently spiral surfaces instead of plane surfaces, as in the case of the rectangular arch, and the delineating and working of these spiral surfaces constitute the principal difference between the oblique and the symmetrical arches in the design and execution of the work. Preparatory to the construction of a skew arch a large drawing

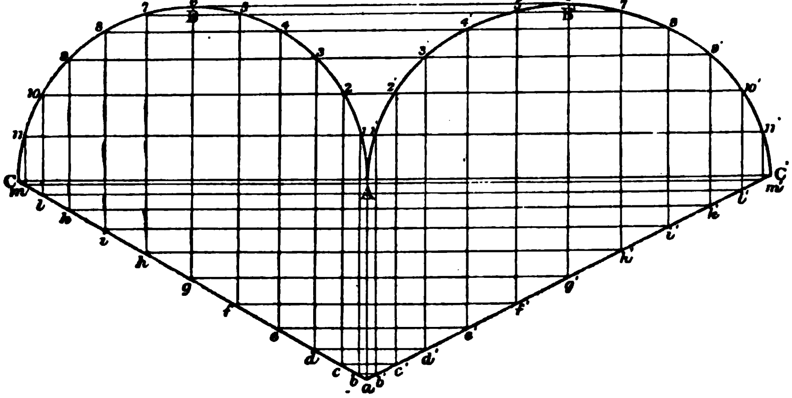
of the soffit must be made, showing the exact shape and position of every arch stone. This drawing is the *development* of the curved surface, that is, it is a representation of that surface as if *spread out flat*. As it is essential that the spiral surfaces should be accurately drawn and worked, it is necessary to possess ready means of determining these surfaces in the drawings with the utmost precision, as well as the dimensions of the templates from which these surfaces are worked.

The spiral form was first introduced by Nicholson, and explained by him in two works entitled Stone-cutting, and A Guide to Railway Masonry, published about the year 1828, and the methods which he employed are still in use almost without modification. Nicholson may indeed be justly regarded as the originator and perfecter of the present system of oblique bridge building, and any treatise upon that subject can hardly be more than an elucidation of the principles and the practice which he laid down and described. These principles and processes we shall now endeavour to explain.

The following processes in descriptive geometry are employed in oblique bridge construction.

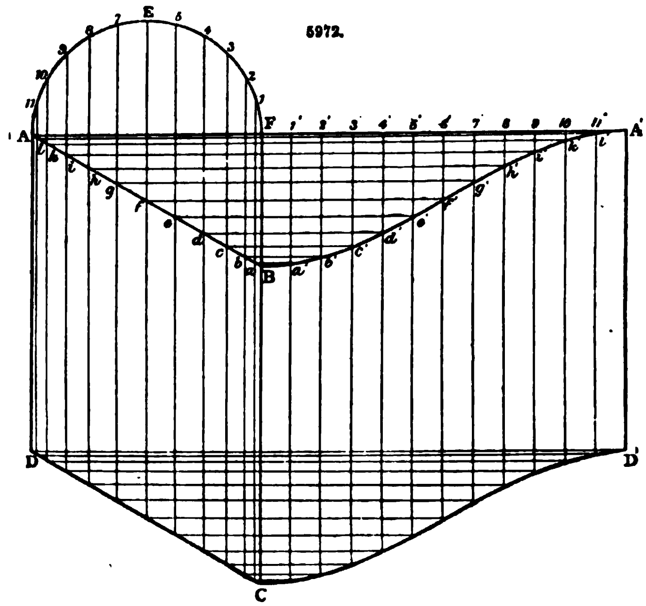
1. *The Right Section of a Cylindric Arch and the Angle of Obliquity being given, to find the Oblique Section.*—Let A B C, Fig. 5971, be the right section of a semicircular arch. Draw the diameter

5971.



A C, and upon the extremity A erect a perpendicular A *a*. From the opposite extremity C draw C *a* to meet the perpendicular in *a*, making the angle A *a* C equal to the angle of obliquity. Produce the diameter C A to C′, and make A C′ equal to C *a*. Join C′ *a*. Divide the arc A B C into any number of parts, as 1, 2, 3, and project these points upon C *a*, as *a*, *b*, *c*, *d*. Project these latter points upon C′ *a*, and from the points of projection in C′ *a* erect perpendicular lines. The intersections of these lines by horizontals to A C′, drawn from the points of division in the arc A B C, will be points in the curve required.

5972.



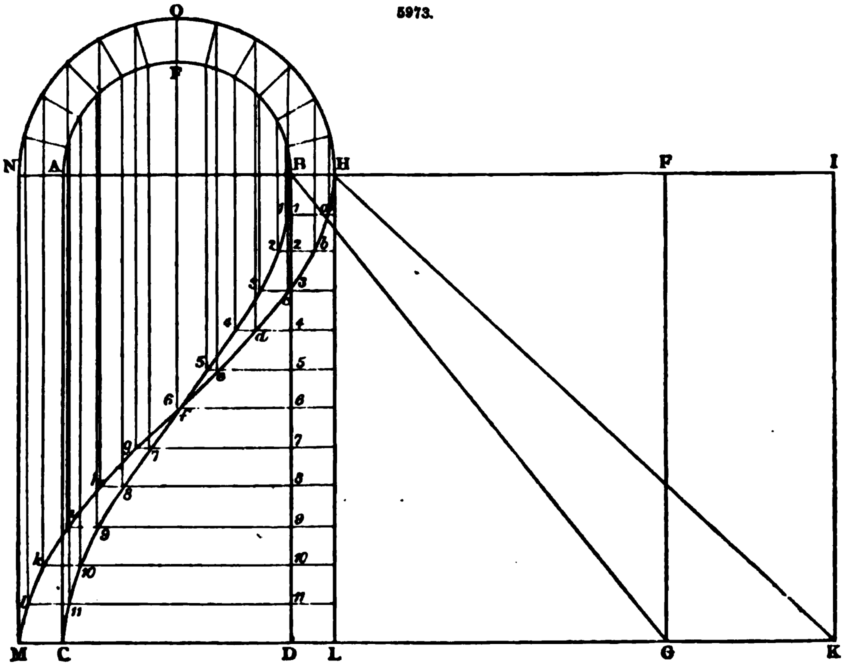
To find the Development of the Curve of the Oblique Section.—Let A B and C D, Fig. 5972, be the plans of the curves of oblique section whose development it is required to determine. Draw A F perpendicular to A D, and upon A F describe the rectangular elevation of the arch A E F. Produce A F to A′, making F A′ equal to the arc F E A. Divide the arc F E A into any convenient number of equal parts, as 1, 2, 3, and the line F A into the same number of equal parts. From these points of division draw lines parallel to A D, and from *a*, *b*, *c*, the points in which these lines meet A B, draw other lines parallel to A F. The points of intersection *a*′, *b*′, *c*′, will be points in the curve sought.

It is obvious that the curve C D′ which is the development of C D, will be equal, similar and

parallel to B A′. Therefore, to obtain this development, repeat the operation upon C D; or, which is often more convenient in practice, transfer the curve B A′ to C D′ by means of a mould.

To Project a Spiral Line upon a Cylindric Surface.—Let A B C D, Fig. 5973, be a semi-cylinder, in this case a right cylinder, of which A E B is the elevation. Divide the arc A E B into any

5973.



convenient number of equal parts, and from the points of division draw lines parallel to A C or B D. Divide B D into the same number of equal parts, and from these points of division draw lines perpendicular to A C or B D. The points of intersection of these two series of lines will be points in the spiral required.

Produce A B, and make B F equal to the arc A E B. Also produce C D, and make D G equal to B F. Draw the diagonal B G. Then the parallelogram B F D G will be the development of the cylindric surface A B C D, and the diagonal B G will be the development of the spiral B C. The angle of the spiral, or angle of the twist, is the angle D B G.

To Project a Spiral Surface.—Let A B C D, Fig. 5973, be the inner surface and N H M L the outer surface of a semi-cylinder, of which A E B, N O H, is the end elevation. Project the spiral H M of the outer surface in the same way as the spiral B C of the inner surface was projected. These spirals will bisect each other, and the space included between them will be the projection of the spiral surface. The breadth of this surface is the thickness B H of the cylinder.

Produce N H, and make H I equal to the arc N O H. Produce likewise M L, making L K equal to H I, and draw the diagonal H K. Then the parallelogram H I L K will be the development of the cylindric surface N H M L, and the diagonal H K will be the development of the spiral H M. The angle of the twist, in this case, is the angle L H K.

As the spirals are all similar and parallel, if we draw all those of the inner surface, or intrados, by means of a cardboard mould cut to B C, and those of the outer surface, or extrados, by means of another similar mould cut to H M, we shall have the whole projection of the screw.

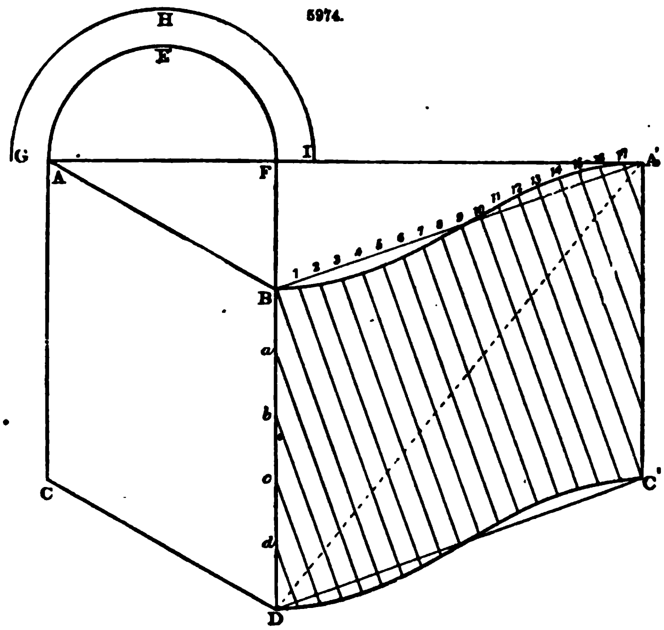
We shall now show how the development and the plan of the soffit and the extrados of an oblique arch are obtained.

Suppose it were required to build a skew bridge over a road, the width of which is A F, Fig. 5974, at an angle equal to A B F. The direct span of this bridge is the distance A F, and the oblique span is equal to $\frac{A F}{\text{sin. } A B F}$, or A B. The skew width of the bridge is the distance A C or B D, and the thickness of the arch, as shown in the end elevation, is A G. It is required to find the development and the plan of the soffit and the extrados of this bridge.

Project, in the way already described, the development of the curves of oblique section A B and C D, and join by straight lines the points B A′, D C′. Upon the extremity B of the line B A′ erect the perpendicular B M. The line B M will show the direction of the coursing joints, and will be the development of the spiral forming the first complete coursing joint. Divide the line B A′ into a sufficient number of parts to represent the several courses of stone, if the arch is to be of stone, choosing an odd number in order that there may be a keystone; and through the points of division draw straight lines parallel to B M, terminating at the curves. These lines will be the developments of the spiral coursing joints; those which intersect the springings, as *a*, *b*, *c*, 9, 10, 11,

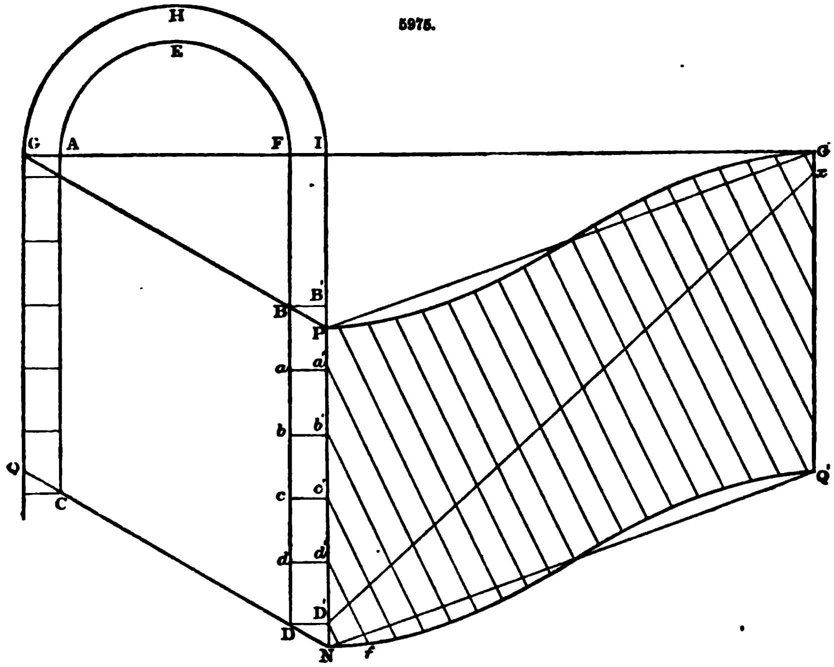
are partial joints, the rest are complete joints. If now lines be drawn from the points a, b, c, parallel to B A′, these will be the developments of the heading joints. The latter, however, are not continuous like the coursing joints, but are drawn in the manner shown in a subsequent figure. The oblique cylindric surface A B D C is the soffit or intrados of the arch, and B A′ C′ D is the development of this surface, which it was required to determine.

5974.



We have now to obtain the development of the extrados, or outer surface of the arch. Upon the direct span A F, Fig. 5975, describe the semicircle A E F, and produce A F to G and I, making A G and F I equal to the thickness of the arch. Upon G I describe the semicircle G H I, and from the points G, A, F, I, draw G Q, A C, F D and I N perpendicular to G I. Draw G P, and make the angle G P I equal to the angle A B F in Fig. 5974, which is the angle of obliquity. Also

5975.



draw Q N parallel to G P at the distance B D in Fig. 5974, which is the skew width of the arch. Then shall A B D C and G P N Q be respectively the soffit and the extrados of the arch, of which A E F and G H I are the rectangular end elevations. It is required to find the development of the surface G P N Q, the extrados of the arch.

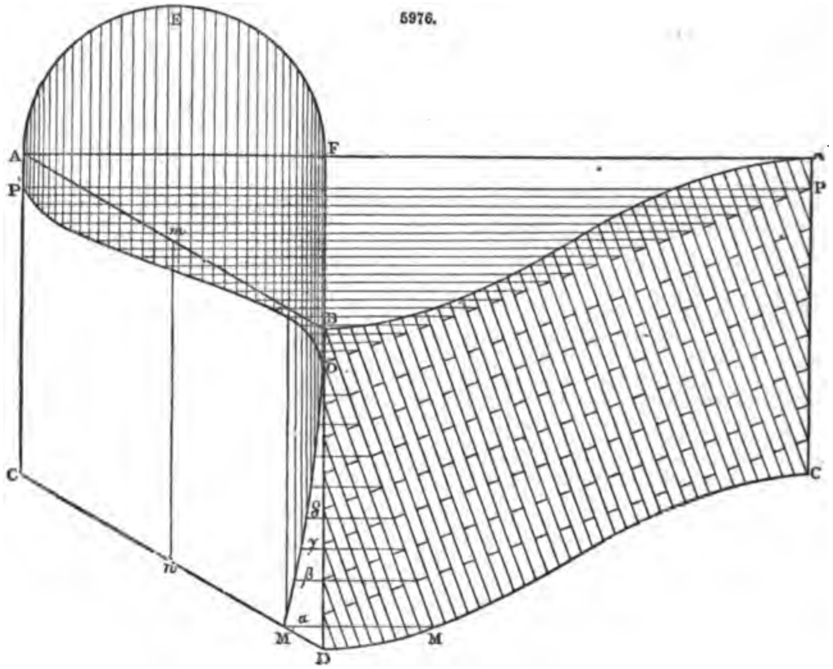
Determine, in the manner already described, the developments of the curves of oblique section G P and N Q, and join the points P G′ and N Q′ by straight lines as before. From the points of division B, a, b, c, d, D, on the line B D draw, perpendicular to B D, the lines B B′, $a\,a'$. Set

off δ upon G′ Q′, a length G x equal to N D′, and join D′ x. Divide the line D′ x into the same number of equal parts as B A′, B D, Fig. 5974, or, which is the same thing, into the same number of equal parts as the dotted line D A′ is divided into by the intersections of the coursing joints. Then, through the points d' and the first division upon D′ x, draw $d'f$, which will give the direction of the coursing joints. The whole of the remaining coursing joints are drawn parallel to this one $d'f$, through the other points of division upon D′ x. If, from the points a', b', c', d', we draw, in the manner shown in the next figure, lines perpendicular to the coursing joints, these lines will be the developments of the heading joints; and P G′ Q′ N will be the development of the oblique cylindric surface G P N Q, which is the extrados of the arch.

In the preceding examples we have supposed the arch to be semicircular; the same principles and processes, however, apply equally to the segmental arch.

It now remains to find the plan of the soffit and that of the extrados. Let A B D C, Fig. 5976,

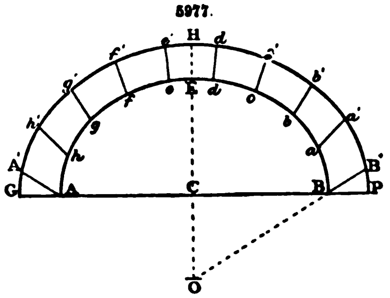
5976.



be the surface of the soffit or intrados, of which B A′ C′ D is the development obtained by the processes already explained. It is required to find upon the surface A B D C the position of the joints shown in the development.

Divide the semicircle A E F into the same number of equal parts as there are in the curve B A′, which parts there represent the coursings, and from the points of division draw lines perpendicular to A F. From each of the heading joints upon the first entire coursing joint B M, draw other lines parallel to A F. The intersections of these two sets of lines will be points in the curve B M′, which is the position on the intrados of the joint B M. The other coursing joints may be projected in the same way; but the readiest method is to cut a cardboard mould of the curve B M′ and to draw the remaining joints from this mould. Next, from the ends of one of the heading joints O P, draw lines parallel to A F. The intersections of these lines with those drawn from the points of division in the arc A E F will be points in the curve O P′, which is the position on the intrados of the heading joint O P. If a cardboard mould of this curve be now cut, the heading joints may be easily drawn upon the intrados. The whole plan of the intrados may be obtained in this way. To obtain the plan of the extrados proceed in a similar manner with the development of that surface.

5977.



We have now to find the elevation of the face of the arch, as dependent on the foregoing principles.

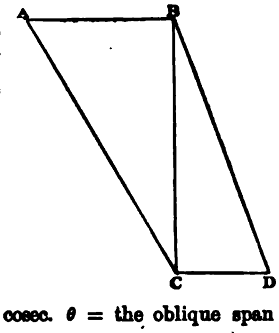
Find the oblique section of the arch A E B, G H P, as shown in Fig. 5977; then the semi-ellipse A E B will be the elevation of the soffit, and the semi-ellipse G H P will be the elevation of the extrados. Divide A E B into parts equal to the divisions on the curve B A′, Fig. 5974, that is, to the courses shown on the development of the soffit. Also divide G H P into parts equal to the divisions on the

curve P G′, Fig. 5975, the development of the extrados. If these points be joined, the lines B B′, $a a'$, $b b'$, will represent the joints in the face of the arch, and the elevation of the face will be complete. The lines B B′, $a a'$, are, however, not straight lines, but curves, concave on the upper side, B B′ being the most concave, and the others diminishing in concavity as they approach the vertex, where it disappears altogether. If a third development were made at half the thickness of the arch, we should have a middle series of points, and thus three points in the curve would be obtained. In a drawing to a small scale the curvature will not be apparent.

Some of the preceding processes of descriptive geometry are difficult of execution in the case of very large drawings, and calculation may then be advantageously substituted for those processes. J. Watson Buck was the first to call special attention to the methods of determining by calculation the several dimensions of a skew arch, and in a work which he has published on the subject he has given some simple formulæ by which those dimensions may be readily and accurately determined. The processes described by Buck have been further simplified by W. H. Barlow; and, thanks to the labours of these engineers, all the angles and dimensions of an oblique arch, as well as the twisting rules and templates used in working the stones, can now be easily obtained by the method of calculation. We shall consider some of the preceding figures in reference to this method.

Let r represent the radius of the cylinder, e the thickness, and θ the angle of obliquity. Then in Fig. 5974, A F $= 2\,r$, F B $= 2\,r \cot.\,\theta$, F A′ $= \pi\,r$, A B $= 2\,r$ cosec. θ, and tan. F A B $= \frac{\text{F B}}{\text{F A}} = \frac{\cot.\,\theta}{\frac{1}{2}\pi}$ = tan. of angle of skewback of intrados. In Fig. 5975, I G′ $= \pi\,(r + e)$, $\frac{\text{cotan.}\,\theta}{\frac{1}{2}\pi}\left(\frac{r+e}{r}\right)$ = tan. of angle of skewback of extrados, and B′ P $= e$ cotan. θ. In Fig. 5977 the lines B B′, $a a'$, which are the chords of the small curves forming the joints in the face of the arch, all radiate from a centre O, the position of which centre may be found either by calculation or by geometry. By similar triangles, B P : P B′ :: B C : C O, or as e cosec. $\theta : \frac{\cot.^2\theta}{\frac{1}{2}\pi}\left(\frac{r e + e^2}{r}\right)$ :: $r \cos.\,\theta : \frac{\cot.^2\theta}{\frac{1}{2}\pi}(r + e) =$ C O. Therefore C O $= r$ cotan. θ tan. ϕ, ϕ being the angle of the skewback of the extrados. Or C O $= (r + e) \cot.\,\theta \tan.\,\beta$, β being the angle of the skewback of the intrados.

5978.



To determine the distance C O geometrically, draw A B, Fig. 5978, $= r + e$; and from A draw A C to meet a perpendicular from B at an angle equal to the angle of obliquity. Also draw B D indefinitely, making the angle C B D equal to the angle of the skewback of the intrados. Then C D drawn perpendicular to B C = C O.

As it is usually desirable to show the curvature of the joints in the face of the arch, a semi-ellipse must be described for the mean thickness, and $r + \frac{1}{2}\,e$ substituted for $r + e$ in the first expression of the value of C O. By this means the intermediate points may be obtained.

Of the preceding formula, those which give the value of C O apply both to the semicircular and to the segmental arch; but the rest apply only to the semicircular. We will now give those which are applicable to the segmental arch.

Let a be the arc of the segment and c its chord. Then c cosec. θ = the oblique span; $c \cot.\,\theta$ = the distance of obliquity; $\frac{c \cot.\,\theta}{a}$ = tan. of angle of skewback of intrados, and $\frac{c \cot.\,\theta}{a}\left(\frac{r+e}{r}\right)$ = tan. of angle of skewback of extrados. Substituting this value of the tan. of the extradosal angle for that given in the formula for the semicircular arch, we have

$$e \cot.\,\theta \times \frac{c \cot.\,\theta}{a}\left(\frac{r+e}{r}\right) = \frac{c.\,\cot.^2\theta}{a}\left(\frac{r e + e^2}{r}\right) = \text{P B}' \text{ in Fig. 5975.}$$

And as

$$e \text{ cosec. } \theta : \frac{c \cot.^2\theta}{a}\left(\frac{r e + e^2}{r}\right) :: r \text{ cosec. } : \frac{c \cot.^2\theta}{a}(r + e) = \text{C O}.$$

When C O has been determined, the only development required will be B A′ in Fig. 5974. It is now requisite to show how the ordinates of this curve are obtained.

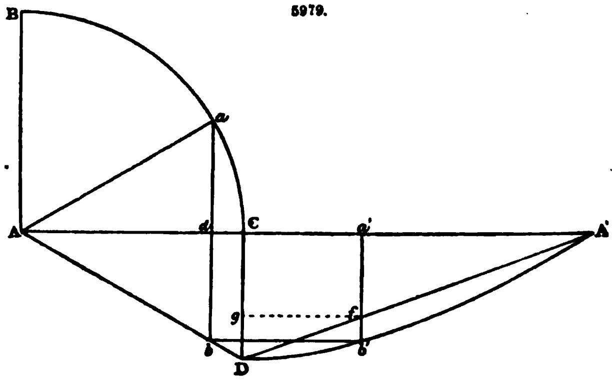
Let B C, Fig. 5979, be the half of a semicircular arch, the obliquity of which is C D A. It is required to obtain the development D b' A′ by calculation. Divide the arc B C, and its development C A′, into the same number of equal parts. Let a be one of the divisions in the arc, and a' its corresponding division on the development; then A′ a' = B a. Also let A B, the radius, be represented by r, the angle B A a by δ, the angle C D A by θ, and the angle C A D by β. We have A $d = r \sin.\,\delta$; $d b = r \sin.\,\delta \cot.\,\theta = a' b'$; A′ a' tan. $\beta = a' f$, and $a' b' - a' f = f b'$.

When a sufficient number of divisions $f b'$, corresponding to equal divisions on the arc B C, or its development C A′, have been obtained, divide D A′ into the same number of equal parts, as shown in Fig 5980, at a, b, c; a', b', c'. The two halves of the curves being similar, it is only requisite to find one half of the ordinates, and to apply them on both sides of the line A B. Therefore, at each of the divisions b, c, d, draw the ordinates $f b'$, Fig. 5979, and make all the angles D $f b'$ equal to the angle C A′ D, the intradosal angle. Through the points thus obtained, draw the curve D b' A′, which will be the development of A D, half the given curve.

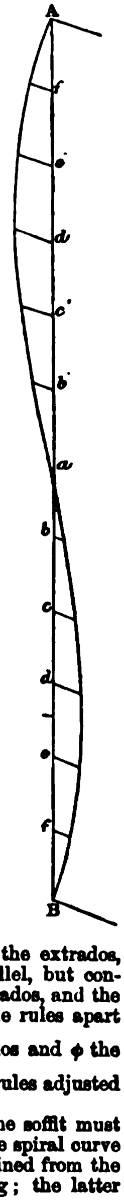
We now come to the consideration of the methods of working the voussoirs preparatory to the

erection of a skew bridge. Evidently the bed of a voussoir is a portion of the spiral surface B H M O, Fig. 5973, and these spiral surfaces on the stones are called winding beds. To obtain

5979.



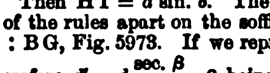
5980



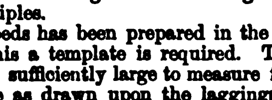
these beds, the workman employs what he calls a winding strip, but which is more generally known by the name of *twisting rules*. These twisting rules consist of two straight-edges held at a determinate distance apart by two light iron rods. One of these straight-edges, or rules, is usually 3 in. broad, and has both its edges parallel; the other is of the same breadth as the first at one end, but increases in breadth towards the other end, according to the angle of the twist. Both rules are equal in length, and that length must be exactly equal to the depth of the voussoirs. To obtain the winding bed, the workman sinks each of these rules into a draft in the stone until their upper edges are in the same plane; their under edges are then in the intended winding bed. The superfluous parts of the stone are then cut away until a straight-edge applied from one draft to the other, and kept parallel to the soffit, everywhere coincides with the surface of the bed.

As the winding beds are cut to the twisting rules, it is essential that these rules be accurately determined and constructed. We shall now show how their dimensions are determined. Let A B C D and E F G H, Figs. 5981, 5982, be the two rules. The edge C D of Fig. 5981 is parallel to the edge A B; but the edge G H of Fig. 5982 is divergent from the edge E F. The breadth E G is equal to the breadth A C, and the breadth F H exceeds the breadth E C by the quantity H I, the value of which depends upon the angle of the twist.

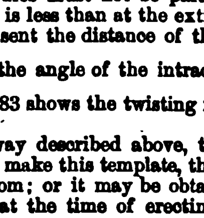
5981.



5982.



5983.



To find the value of H I, let d represent the distance of the rules apart at the extrados, and δ the angle of the twist. Then $HI = d \sin.\ \delta$. The rules must not be parallel, but convergent; that is, the distance of the rules apart on the soffit is less than at the extrados, and the difference is in the ratio H K : B G, Fig. 5973. If we represent the distance of the rules apart on the soffit by d', we have therefore $d' = d\,\dfrac{\sec.\ \beta}{\sec.\ \phi}$, β being the angle of the intrados and ϕ the angle of the extrados, as in the formula given above. Fig. 5983 shows the twisting rules adjusted in accordance with these principles.

When one of the winding beds has been prepared in the way described above, the soffit must next be obtained, and to do this a template is required. To make this template, the spiral curve must be developed to a scale sufficiently large to measure from; or it may be obtained from the course lines and the face line as drawn upon the laggings at the time of erecting; the latter is the readiest mode for the workmen.

It is a somewhat difficult matter to shape the stones which form the face of an oblique arch with such accuracy that they shall not require to be pared after being set. The following method of obtaining the template for each quoin stone was first published in the Civil Engineer and Architects' Journal for 1841, and though others have been resorted to since, the merit of being the readiest and the most expeditious must still be claimed for this one.

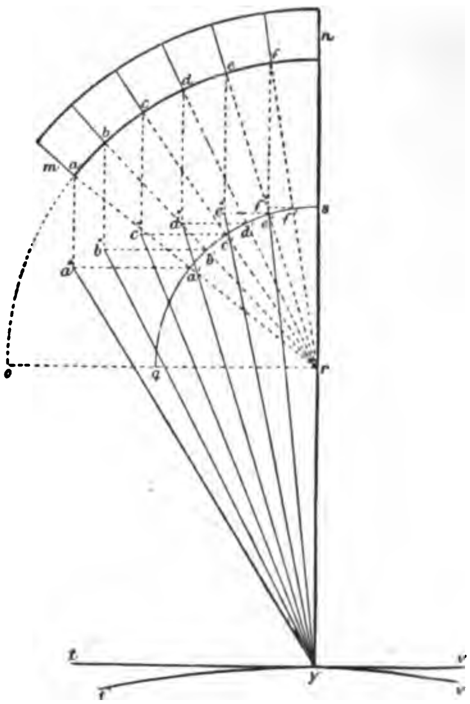
Let $m\,n$, Fig. 5984, be the elevation of the half arch on the square, and $o\,r$ its radius. Make $r\,s$ = radius × sin. β, and with the distance $r\,s$ as a radius, describe the arc $q\,s$. Produce $n\,r$ to y, making $r\,y = \text{radius} \times \dfrac{\sin.\ \phi}{\cot.\ \theta \times \tan.\ \phi}$. From the joints $a\,b\,c\,d\,e\,f$ draw lines to the centre r, intersecting the arc $q\,s$ $a'\,b'\,c'\,d'\,e'\,f'$. From the points $a'\,b'\,c'$, &c., draw horizontal lines, and from the points $a\,b\,c$ draw vertical lines, intersecting the former in $a''\,b''\,c''\,d''\,e''\,f''$. And from these last points draw

lines to y, as shown in the figure. Then applying the curve of the intrados, so that $t\,v$ is a tangent to it at y, the templates for each stone will be found from the figure.

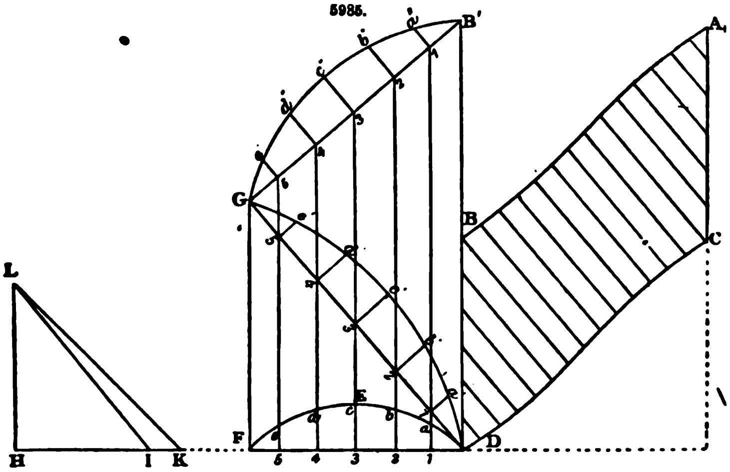
The following is another method of obtaining the templates for working the beds and soffits of the arch stones, directly from the drawing of the development of the intrados. Let A B C D, Fig. 5985, be the development of the intrados, of which the semicircle D E F is the right elevation. Erect F G perpendicular to D F, and draw D G parallel to the coursing joints meeting F G in G. Draw G B′ parallel to B A, to meet D B produced. From the points of division in the arc D E F, erect lines parallel to F G; these lines will cut D G and B′ G in the points 1, 2, 3. From these points, and perpendicular to D G, and B′ G, draw 1 a', 2 b', 3 c', 1 a'', 2 b'', 3 c'', equal to 1 a, 2 b, 3 c, the distances from the chord to the points of division in the arc D E F. Draw, through the points thus obtained, the curves D a' b' c', G, and B′ a'' b'' c'', G. From these segments the arch-curves or bevels may be constructed, by making the inner edge of the curved limb in Fig. 5986 identical with the half segment of G B′, Fig. 5985, and the inner edge of the curved limb in Fig. 5987 identical with the half segment of G D, Fig. 5985. The inner edge of the other limb of the bevels is straight.

To find the angle of the twist, produce D F, Fig. 5985, to H, and upon F H set off H I equal to the radius of the arc D E F. From the point H erect H L perpendicular to F H, and from the point I draw I L parallel to D G, which is parallel to the coursing joints in the development A B C D, meeting H L in L. From I set off I K

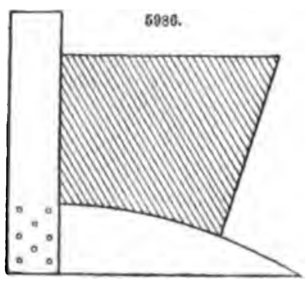
5984.



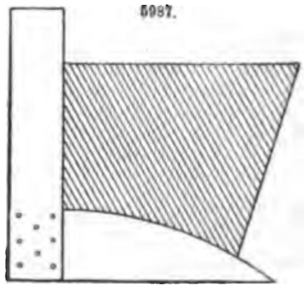
5985.



5986.



5987.



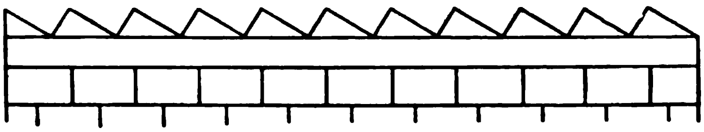
equal to the breadth of the beds of the stones, and join K L. The angle I K L is the angle of the twist.

We shall now show how one of the arch stones is worked by means of the templates obtained in the manner described above. Suppose the stone, all the faces of which are rectangular, to be lying upon one of its beds, with the soffit next the workmen, and consequently its other bed uppermost. Having applied the template D G, Fig. 5985, in such a way that the curved edge may rest upon each end of the nearest arris, draw a line upon the surface of the stone by the curved edge of the template. This line will be the bed line between the soffit and that bed. It must be observed that the curve will be concave to the adjacent arris of the stone. The twisting rules must now be applied in such a way that the parallel rule shall rest upon the nearest arris that is to be cut away, and the rule containing the angle of the twist be at a distance equal to the intended breadth of the bed. The latter rule must then be sunk into the stone until the upper edges of the two rules are out of winding. The bottom of the chisel draft will make an angle with the surface of the stone equal to the angle of the twist. The superfluous stone between the draft and the bed line is to be cut away, until the surface everywhere agrees with a straight-edge applied from any point perpendicular to the curve forming the bed line.

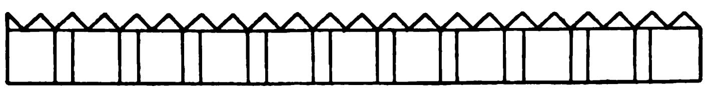
When one winding bed has been worked, the next step is to form the soffit. This is done by applying the bevel shown in Fig. 5987 in the same way as a common square is applied. Each limb of the bevel is to be perpendicular to the arris, or to a tangent to the curve which forms the arris or bed line, so that the straight-edge may coincide with the surface of the bed, and the curved edge rest upon the superfluous stone of the soffit which is to be cut away. The stone is then worked off until the curved edge of the bevel coincides with the surface of the soffit, which will be that of a cylinder. The soffit must then be gauged to its breadth, and the other winding bed worked with the same bevel. The curved edge is, of course, applied to the soffit, and consequently the straight-edge will be upon the winding bed. It may be remarked here, that the method of working the beds of the voussoirs forming the face of the arch in such a way that the joints shall be at right angles to a tangent to a curve at that point, though generally adopted by engineers of all countries, seems objectionable on the grounds of insecurity and difficulty of execution.

The impost upon which the arch rests must be divided into as many equal parts as there are courses intersecting the springings, and as many triangular checks sunk in it. Fig. 5988 is an

5988.

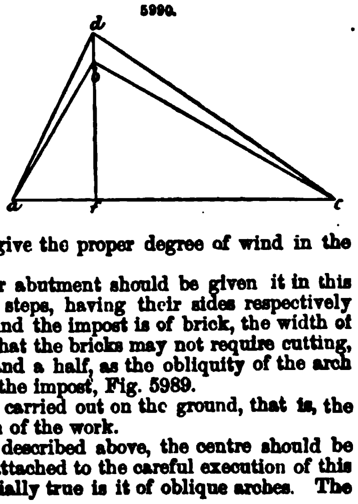


5989.



elevation, and Fig. 5989 a plan of the impost parallel to the axis of the cylinder, the number of checks in this case being eleven. To mark these checks upon the springing stone, triangular templates of sheet iron or wood are required. These templates are obtained in the following manner. Construct a right-angled triangle, Fig. 5990, having the side $a\,c$ equal to the length of the check on the impost, and the side $a\,b$ equal to the thickness of the courses. This will be the triangle of the intrados. To obtain the triangle of the extrados, let fall the perpendicular $b\,f$, and produce $b\,f$ to d, making $f\,b : f\,d :: r : r + e$; r being the radius of the cylinder and e its thickness. Join $d\,a$ and $d\,c$. These triangles, cut out in wood or sheet iron, will be the templates required. To use the templates, apply them with the side $a\,c$, or hypothenuse downwards, and, keeping the extremities a and b against each of the divisions in succession, score by the perpendicular and the base. The back or extrados of the impost must, of course, be marked from the template of the extrados. The difference in the angle of the two will give the proper degree of wind in the bed and the cross joints of the checks of the impost.

5990.



As the thrust of the arch is parallel to the face, a proper abutment should be given it in this direction by working the back of the impost in vertical steps, having their sides respectively parallel and perpendicular to the face. When the wall behind the impost is of brick, the width of the step at right angles to the thrust should be made such that the bricks may not require cutting, that is, it should be made to correspond to a brick, a brick and a half, as the obliquity of the arch may require. These vertical steps are shown in the plan of the impost, Fig. 5989.

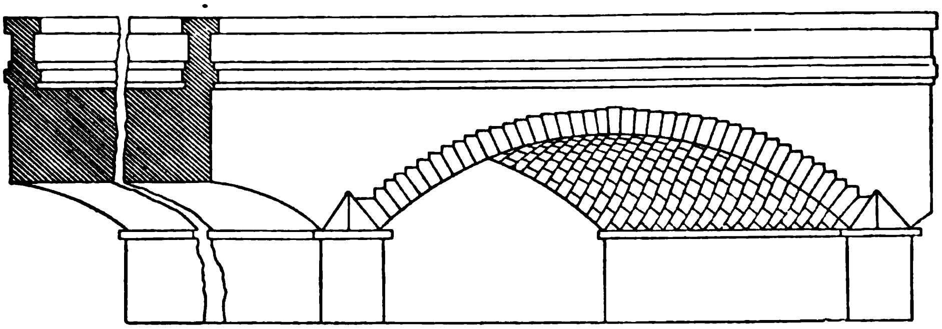
It now only remains for us to describe how the design is carried out on the ground, that is, the practical methods adopted for ensuring the correct execution of the work.

When the imposts have been prepared in the manner described above, the centre should be erected and well lagged. Too much importance cannot be attached to the careful execution of this part of the work. This is true of all arches, but more especially true is it of oblique arches. The

laggings should be evenly and firmly fastened down, and they should be long enough to project a few inches beyond the faces of the arch. The spiral joints must then be marked upon the laggings to guide the masons in setting the voussoirs. For this purpose a long, flexible straight-edge must be procured. This straight-edge is usually a ½-in. deal board, about 12 in. broad and 25 ft. long, having one or both of its edges perfectly straight. It should be sufficiently long to reach from the impost to the crown, that is, it should be equal in length to half the heading spiral. The lines for the face, which are perfectly straight on the plan, should be first drawn on the laggings; these are the lines A B, C D, Fig. 5976. Then bisect each face, and draw the line *m n* through the points of bisection, and divide this line similarly to the impost; in other words, divide it into parts corresponding to the checks upon the impost, α, β, γ, &c. Having divided the straight-edge into the number of voussoirs in the half arch, which will be half the number in the whole arch with half the keystone, if there is one, apply it from the first check on the impost to the corresponding division on the crown, and draw a line on the lagging. Upon this line, while the straight-edge is in the same position, mark with a point the divisions of the voussoirs. Draw all the spirals from the impost to the crown in this way, and mark the divisions of the voussoirs again upon the heading spiral next to the opposite face. The lines thus drawn are the heading spirals. To draw the coursing spirals, begin at the obtuse quoin, and with a straight-edge draw a line on the laggings from the bottom of the first skewback on the impost to the first division on the heading spiral representing the coursing joint. Repeat this operation for all the divisions, and the whole of the coursing-joint spirals will be thus obtained. In the case of an arch built wholly of stone, these lines coincide with the bed-joints of the voussoirs; but when the arch is built wholly or partially of brick, they are the lines to which the courses of bricks must be parallel. When the imposts and the quoins forming the ringstones and head of the arch are of stone, and the intermediate parts of the courses are of brick, the thickness of the courses will be dependent on the thickness at the abutment, say three or four courses of brick to each stone springer. To give the soffit of the arch a good appearance, the brickwork should have a regular half-brick bond throughout. The accuracy of the brickwork requires to be frequently tested during the execution of the work.

We shall now give an example of the application of the preceding processes and formulæ; and shall take, for purposes of illustration, a bridge designed by G. G. André to carry a railway over a street 30 ft. broad, with a footway 15 ft. broad on each side, the angle of obliquity being 50°, Fig. 5991.

5991.



We have in this case;—Direct span = 30 ft., and angle of obliquity = 50°. The oblique span is thus c cosec. $\theta = 30 \times 1 \cdot 3054073 = 39 \cdot 16$ ft. The rise of the arch is 8 ft. Hence the radius $= \dfrac{8^2 + 15^2}{8 \times 2} = \dfrac{289}{16} = 18 \cdot 06$ ft. The thickness of the arch is 2 ft., and the external width is 24 ft. We have now to find the length of the arc a. Dividing the half chord by the radius, we have $\dfrac{15}{18 \cdot 06} = \cdot 8305642 =$ sine of half the arc $= 56° \; 9' \; 24''$. Therefore the whole arc is $56° \; 9' \; 24'' \times 2 = 112° \; 18' \; 48''$, the length of which to radius unity, as found by the tables, is $1 \cdot 960$, and $1 \cdot 960 \times 18 \cdot 06 = 35 \cdot 39$ ft. The tangent of the angle of the skewback of the intrados $= \dfrac{c \text{ cot. } \theta}{a} = \dfrac{30 \times \cdot 8390996}{35 \cdot 39} = \cdot 711302 = 35° \; 25' \; 33'' = \beta$. Hence the length of the heading spiral is a sec. $\beta = 35 \cdot 39 \times 1 \cdot 2271948 = 43 \cdot 43$ ft. A convenient number of voussoirs will be 41. Therefore the thickness of the courses will be $\dfrac{43 \cdot 43}{41} = 1 \cdot 06$ ft. The length of the impost is $b \times$ cosec. $\theta = 24 \times 1 \cdot 3054073 = 31 \cdot 33$ ft.; and the divergence of the courses is impost $\times$ sin. $\beta = 31 \cdot 33 \times \cdot 5796485 = 18 \cdot 159$ ft. This length corresponds to the thickness of seventeen courses, which will be the number intersecting the springing.

The distance C O below the axis of the cylinder, calculated by Buck's formula, would be $\dfrac{c \text{ cot. }^2\theta}{a}(r \times e) = \dfrac{30 \times (\cdot 8390996)^2}{35 \cdot 39} \times (18 \cdot 06 + 2) = 12$ ft.

The tangent of the angle of the extrados may be found from the tangent of the intrados by proportion; thus, $\dfrac{r + e}{r}$ tan. $\beta =$ tan. $\phi = \dfrac{18 \cdot 06 + 2}{18 \cdot 06} \times 711302 = \cdot 7950000 =$ tan. $38° \; 29' \; 6''$. The difference of the angles $(38° \; 29' \; 6'') - (35° \; 25' \; 33'') = 3° \; 3' \; 27'' = \delta$, the angle of the twist.

The twisting rules for working the winding beds of the voussoirs must be equal in length to the depth of the latter; therefore in this case they will be 2 ft. long. The distance apart at which they are applied on the extrados is 2 ft. 6 in. = 30 in. The additional breadth to be given to one end of the twisting rule will thus be d sin. $\delta = 30 \times \cdot 0533380 = 1 \cdot 6$ in. Hence, if the narrow end be 3 in., the broad end must be 4·6 in. The distance apart at one end being 30 in., the distance at the other will be $d' = d \dfrac{\sec. \beta}{\sec. \phi} = \dfrac{30 \times 1 \cdot 2271948}{1 \cdot 2775126} = 28 \cdot 8$ in.

The triangular templates for marking the checks on the springing stones will be obtained by making the base = 1·06 ft., and the hypothenuse = the length of the check on impost.

OPTICAL INSTRUMENTS. Fr., *Instruments d'optiques*; Ger., *Optische Instrumente*, Ital., *Strumenti ottici*; Span., *Instrumentos ópticos.*

See Surveying Instruments.

ORDNANCE. Fr., *Pièces d'artillerie*; Ger., *Artillerie, or Geschützkunst*; Ital., *Artiglieria*; Span., *Artilleria.*

Ordnance is a term synonymous with artillery, and includes all heavy weapons of warfare.

See Artillery. Gun Machinery. Gunnery.

ORES, Machines and Processes employed to Dress. Fr., *Préparation mécanique des minérais*; Ger., *Mechanische Aufbereitung der Erze*; Ital., *Macchine e procedimenti per lavorare il minerale*; Span., *Maquinaria y procedimiento empleados para preparar minerales.*

In the preparation of certain metallic ores for smelting purposes it is often expedient to use machines which are specially adapted to economize labour and to obtain the largest possible yield of the particular metal or metals sought, by separation from the extraneous minerals such metal may be associated with.

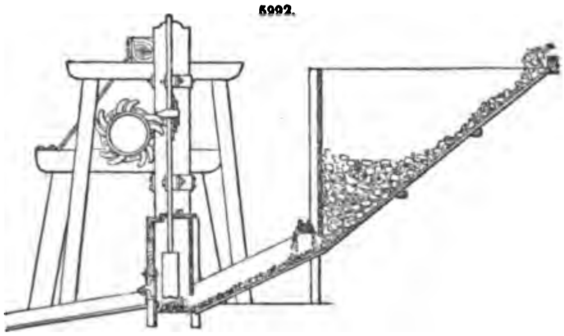
The following description of dressing tin and copper ores in Cornwall, read by James Henderson, before the Institute of Civil Engineers, in 1858, gives an excellent idea of the general nature of the machinery and processes employed to dress ores;—

Tin Dressing.—The stones of tin ore, on coming from the mine, are ragged and spalled, or broken to a size not exceeding that of a man's fist. After undergoing this process, the agent, or head dresser, in order to form some idea of its quality, proceeds, in all probability, to van a small portion. This consists in bruising some of the ore, on a shovel, to a very fine powder, when, by immersing the shovel in water, from time to time, in a horizontal position, and giving it subsequently an undulating and circular motion, the light earthy and stony particles are gradually carried over the edge, leaving the tin and other minerals to settle on the shovel, according to their specific gravity.

It may be remarked that the tin in the stone, unlike the ores of copper, requires an experienced eye to detect its presence. The ore of tin, which in Cornwall is almost invariably the peroxide, has a specific gravity of about 6·50. The minerals usually associated in the stone with the tin are iron pyrites, or mundic, which is frequently arsenical, possessing a specific gravity of 4·90; copper pyrites, or yellow ore, having a specific gravity of 4·25; and the inveterate foe of the tin dresser, wolfram, or tungstate of iron and manganese, having a specific gravity of nearly 7·00. Thus it will be seen that the tin ore, if in sufficient quantity, will, by the process of vanning, be separated readily from the yellow ore and mundic, whilst the wolfram will remain. Hence the dislike which the tin dresser has to that mineral; for with every care in the numerous manipulations to which the ore is subjected, the wolfram will cling to the tin, resisting even the roasting operations to which the greater part of the tin ore in Cornwall is submitted, before it is considered fit for the smelting house.

After being spalled the ore is either measured, or weighed, according to the usage of different mines, and about a barrowful is broken with flat-headed hammers, on an iron plate, to the size of gravel, when, according as to whether weight or measure is to be applied, a quarter noggin, or an ounce weight, is bruised down and vanned, to ascertain the value of the whole. If the tin is associated with copper, or iron pyrites, the ore is roasted on the vanning shovel, or in a crucible, and the sulphur and arsenic in the pyrites being thereby sublimed, the copper on the van being again washed, is carried over the edge of the shovel; the remainder of the iron in the pyrites being now freed from its impurities, is readily removed by the application of a magnet to the dried ore. Pure black tin, or peroxide, is now all that remains.

5992.



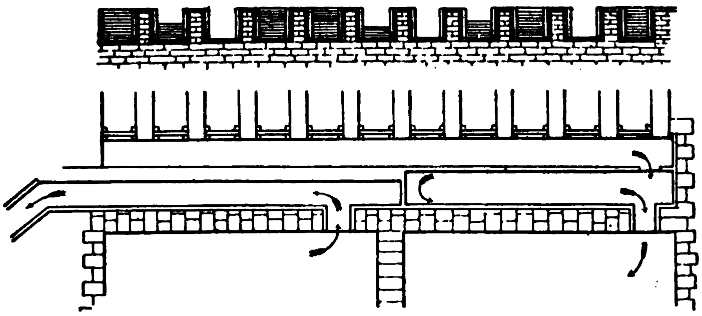
When the spalling process has been completed, the stones of ore are taken in carts, or conveyed by tram-wagons, to the back of the pass, behind the stamping mill.

The stamps, Fig. 5992, consist of a number of heavy rectangular blocks, of cast iron, weighing from 1½ to 5 cwt. each, called stamp-heads, which are alternately lifted by cams, or wipers, fixed at regular intervals on a horizontal axle, placed in front of or behind the lifters to which the stamp-heads are attached. There are generally four stamps in a set, and the number of sets varies according to the requirements of the mine, or to the power employed. The height to which the stamp-heads are raised, by the tongue attached to the lifters, is usually about 10 in., and the speed sixty blows

a minute. These, then, fall with repeated blows on the tin ore, which, having passed gradually from behind, down an inclined plane, underneath the stamp-heads, by its own gravity, aided by a stream of water and the constant vibration of the machinery, soon becomes completely pulverized, and at each blow of the stamp-heads flashes up in a liquid state, through four perforated plates, technically called grates, two of which are fixed in the front and one at each end of the wooden chest in the stamps work. The holes in these perforated plates vary in size from the diameter of a small needle, to that of a pin's head; and much judgment is required in the selection of the grate best adapted to the quality of tin stuff to be dressed. They are usually made of pieces of thin sheet iron, about 9 in. square, the holes are punched on the convex side, and the concave side is turned towards the stamps. When in constant work the grates generally last about a fortnight; but sometimes, when they become corroded by acid in the water, which in some mines is frequently the case, they will only last twenty-four hours, and under such circumstances copper grates are employed. In some instances the grates are entirely dispensed with, and the pulverized mineral is projected over a small wooden shutter, fixed in lieu of a grate. This shutter is raised or lowered in the grate-holes, according as the tin ore is required in a fine or a rough state.

The tin ore after being stamped, and having passed through the grates, in the form of fine sand and water, is conveyed down a short incline, about 12 ft. long, into long wooden troughs, called strips, which are wooden troughs from 35 ft. to 40 ft. in length, 18 in. wide, and 15 in. deep, with a fall of about 1 ft. in the total length. There are usually three strips to each set of four stamps. In these the tin ore is deposited, according to its specific gravity; the best, or heaviest, tin being left at the head, whilst the finer and lighter portion is carried towards the tail. The strips are open at the lower end, but as they become gradually filled by the deposit of tin ore, slips of wood, about 1 in. in depth and thickness, are slid down horizontally at the tail end of the strips, in a groove at each side. Figs. 5993, 5994, show an elevation of the end, and a plan of the lower portion of the

5993.



5994.

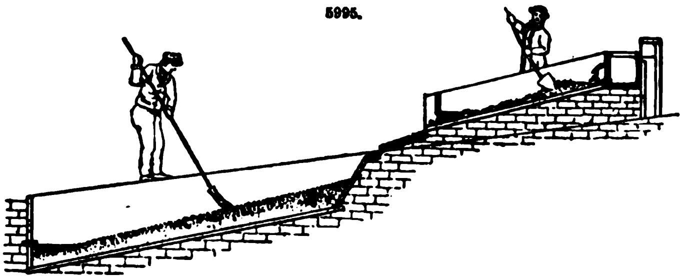
strips, some being represented full, others partially, and some entirely empty. When the strips are full, the contents are divided into three portions, the head, the middle, and the tail, according to the quality of the ore. The slime forming a fourth portion of the tin stuff passes into another pit. The head, or crop, which occupies about 14 ft. of the strips, is wheeled in barrows to square, or more correctly speaking, rectangular buddles: the heads of two strips being generally supplied to each buddle.

Buddling.—The old-fashioned form of buddle, which is still frequently used, consisted of a wooden box about 8 ft. in length, 3 ft. wide, and from 2 ft. to 2 ft. 6 in. deep, sunk in the ground, and having an inclination of about 2 ft. in its whole length. Fixed across the upper end, and above the edges of the buddle, is a board, about 15 in. wide, called the jagging board, or buddle-head, rather more inclined than the buddle itself, on which a small stream of water is made to run, at the will of the buddler, spreading itself thinly over the whole length of the board. The buddler, a man or a boy, standing in the buddle, places on the jagging board a small quantity of the ore, marking it into furrows, or jagging it with the edge of his shovel; and the water above referred to carries it away, gently, into the buddle beneath, where it spreads itself over the bottom of the buddle, assisted by the operator by means of his shovel and his feet, which are shod with a wooden-soled shoe, termed a brogue. In the buddle, Figs. 5995, 5996, the buddler does not jag the ore on the buddle-head, as previously described; but the tin stuff, after being stirred up by an assistant, passes through the perforated plate, Fig. 5996, in a liquid state, and is diffused over it by means of numerous strips of wood, or guides, and falling into the buddle, is carefully and continually swept with a brush, or broom, by the buddler, who stands on a board placed across the buddle. This brushing, like the use of the shovel and brogue, tends to spread the tin ore evenly over the bottom of the buddle. At the lower end, or tail-board, is a vertical row of holes, a few inches apart, through which the surplus water flows, and which are, one after the other, stopped up with plugs as the work rises. About 9 in. in length of water is kept between the work and the tail-board of the buddle, to prevent the escape of any of the ore through the holes. The object of buddling is to separate the rough matrix from the tin. Four and a half buddlefuls are generally finished by two operators in ten hours. The buddle, when filled, is divided perpendicularly into four parts, the head, the fore-middle head, the hind-middle head, and the tail. The head, which generally occupies about one-third of the length of the buddle, is then buddled again, and divided into four parts, which are named as before. The head of the second buddling is then tossed.

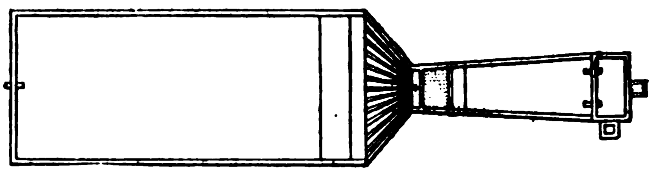
Tossing.—This process is carried on in the following manner;—A large circular tub, about

8 ft. 8 in. in diameter, termed a kieve, is nearly half filled with water. The ore to be tossed is placed gently down the side of the kieve into the water, which is constantly stirred with a shovel,

5995.



5996.



until the water rises, from the addition of the tin stuff, to within 2 in. of the top of the kieve. The tosser always stirs the ore in one direction, thus giving it a circular motion. As the object of buddling was to separate the rough poor matrix from the tin, so that of tossing is to get out the fine matrix. The kieve being now full, the operation of packing at once begins.

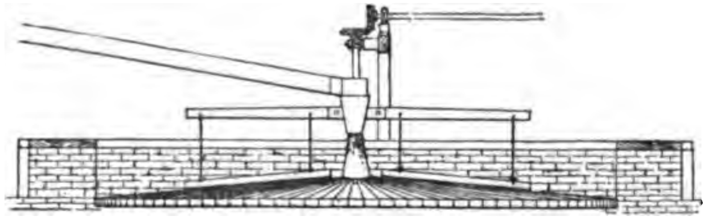
Packing is a very simple process, and merely consists in striking repeated blows on the edge of the kieve with an iron bar, one end of which rests on the ground. About a quarter of an hour is usually occupied in packing, although sometimes an hour may be requisite, according to the nature of the stuff, the fine tin stuff taking a longer time to pack than that of rougher quality. The vibration imparted by the process of packing to the contents of the kieve causes the subsidence of the tin stuff, according to its specific gravity, with greater regularity than it would have done had it been at once left at rest after tossing. In one or two of the Cornish mines, a wooden mall, or hammer, worked by machinery, attached to a water-wheel, is used for packing, and would appear to answer the purpose completely. When the process of packing is completed, which is ascertained by feeling the degree of hardness of the subsidized tin stuff with a shovel-hilt, the water is baled out into a second kieve, placed alongside, where tossing some fresh tin stuff is again carried on. The top part, which is light and inferior, and is called skimpings, is removed with a shovel, to the depth of ½ in. or ¾ in., and is buddled again twice over, and divided into three parts as before; or, according to the nature of the ore, perhaps taken to the frames. The bottom part, termed whits, is then fit for burning in the oven.

The fore and hind middle-heads of the first buddling are now buddled over again, separately from each other, but with the addition of stuff of a similar quality from the other buddles. The tails from the buddles are thrown into a launder, or wooden trough of running water, and are carried by it to the separator, a machine having for its object the separation of the slime tin which the buddle would not retain. The simple test, by vanning the quality of the ore, is applied from time to time, during the dressing operations, and thereby the proportion of heads and tails, and other divisions of the work, according to its richness, are ascertained.

The portion of the tin ore from the stamps, termed the middle of the strips, occupying generally about 18 ft. or 20 ft. of the strips, is thrown into launders of running water, and conveyed by the stream into circular buddles.

Circular Buddles.—The circular buddle, Fig. 5997, is a pit about 18 ft. in diameter, and about

5997.



2 ft. deep at its circumference; the bottom, which is boarded, rising towards the centre about 1 ft. In the centre is fixed a cast-iron cone, down the sides of which the triturated ore, in a very fluid state, flows from the launder, or wooden shoot, before described, and spreads itself over the bottom

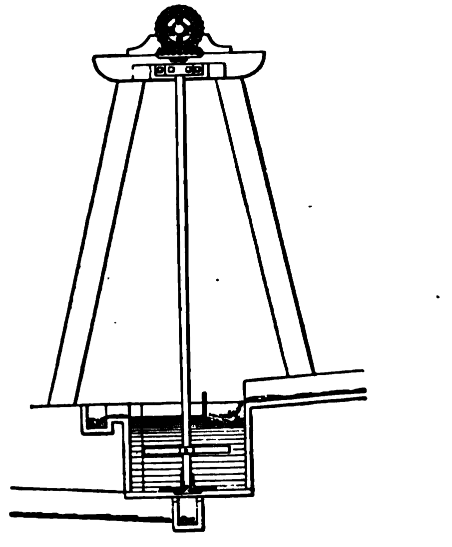
of the buddle. Two wooden arms are, in the meantime, slowly turned by the toothed wheels, and trailing after them a light board, attached to each, spread evenly the ore over the floor of the buddle, which takes about five hours to fill. One circular buddle contains, when full, the middles of about ten strips. When filled, the contents of the circular buddle, which reach to the top of the cone, are divided, perpendicularly, into two parts, the head and the tail, the division being, generally, about half-way in the buddle. Whilst in operation, a breadth of 9 in. of water is kept between the work and the circumference of the buddle, for a similar reason to that described in the operation of the square buddle. The head is thrown into a launder of running water as before, and is conveyed into a second circular buddle, where it undergoes a similar process to that in the first. The tail is sent down another launder to the separator.

The contents of the second circular buddle are divided into three parts, the head, the middle, and the tail. The head occupies 3 ft., the middle 1 ft. 6 in., and the tail the remainder. The head and middle-head of this buddle are wheeled in barrows to a square one, and buddled separately; whilst the tail, like that of the first, is conveyed, by a stream of water, to the separator. The head of the square buddle is tossed and packed, and divided as before, when it becomes fit for the burning house, or oven. The middle head from the square buddle is again buddled, as many times as may be necessary; the tail of each operation passing to the separator.

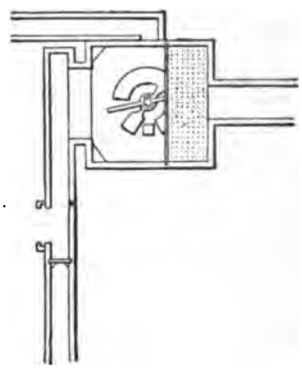
The tail of the strips is thrown into a launder of water, into which the surplus water from the stamps, after passing through the strips, flows, mixed with the light particles, or slimes. It then passes, rapidly, into a small pit, or cover, where some portion of tin is deposited, to be afterwards submitted to the separator. From this cover the water and slimes flow into slime-pits, about 15 ft. long by 12 ft. wide, Fig. 5994. The course that the water, holding the fine ore in suspension, is made to take, is shown by the arrows. As soon as the first pit is full, the slimes pass over into the next pit. The contents of the first pit will, of course, be of better quality than those of the second; whilst the overflow from the second is almost worthless, but it is nevertheless used for supplying the frames, so that no particle of tin may be lost. The two slime-pits are filled in about twenty-four hours.

The Separator, Figs. 5997A, 5997B.—This machine consists of a wooden box, or cistern, into which

5997A.



5997B.

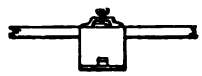


the tin stuff to be separated flows. It has an aperture at the bottom, about 1 in. in diameter, which, by means of an iron disc, or plate, is alternately closed and opened, as the shaft to which the plate is attached revolves. To this shaft is also fixed an iron paddle, which, turning round, keeps the ore suspended in the water in constant agitation. Thus the tails from the different buddles, as well as the contents of the cover at the end of the strips, flow with rapidity into the separator. The rougher and heavier portion passes through the hole at the bottom of the cistern, down a long strip, where it is continually stirred to cause it to be evenly deposited, and also to assist in carrying off the lighter particles. The overflow containing the fine tin, which may be almost considered to float on the water, passes into two catch-pits. The rough part of the contents of the first pit is buddled as many times as may be necessary; whilst the finer portion, with the whole of the contents of the second pit, is wheeled to the frames. When the strip into which the rough portion, termed rows, falls from the separator is full, which is in about four days' time, it is cleaned out, and the contents thrown into a launder of running water, which carries it to another long strip. This, when filled, is divided into two portions, the head and the tail. The head is taken to the stamps, and again stamped with rough tin stuff. The tail is again stripped in the same strip, until it is clean enough for the stamps. The overflowing turbid water is thrown away. The tin in this strip generally averages as much as 3 per cent., so difficult is it, after all the processes to which the ore has been subjected, to extract the whole of the tin it contains.

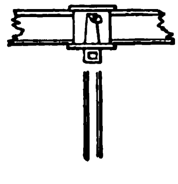
J. B. Wilkins' separator, Figs. 5998 to 6000, is used for the same purpose as the one already described. A stream of pure water is conveyed by a pipe, or small launder, into a small cistern, into which the tin stuff flows, and being admitted close to the bottom of the cistern, boils up through the tin stuff. This not only keeps it in a state of agitation, but prevents all but the rougher and heavier particles passing through the orifice at the bottom, the lighter portions flowing over into two catch-pits, as in the former description of separator. Previous to the operation of framing, to which allusion has been made, the contents of the slime-pits, Fig. 5994, are thrown into a launder of water, and conveyed into a cistern, or cover, at the head of some long and narrow pits called trunks. In this cover the operation of trunking is carried on. This consists in the agitation of the contents of the cover, or slimes, by means of wooden paddles attached to an arm, which, by means of a lever, acted on by a lifter on the axle of a water-wheel, makes a quarter revolution at intervals, thereby moving the paddle to and fro, and causing the slimes which continually supply the cover to flash over into the trunks below them. At the end of each trunk there are holes as in the square buddles, which are gradually plugged up as the stuff rises, permitting the egress of the surplus water into a leat, or water-course. This being considered valueless, is allowed to flow.

5998.

5999

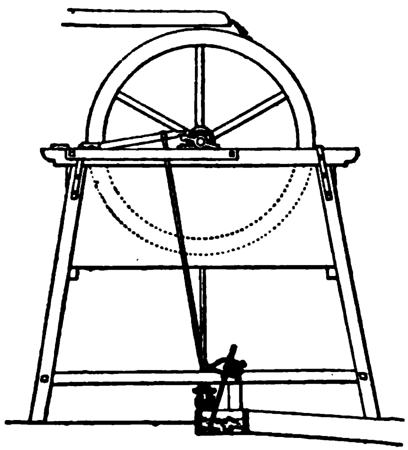


6000.

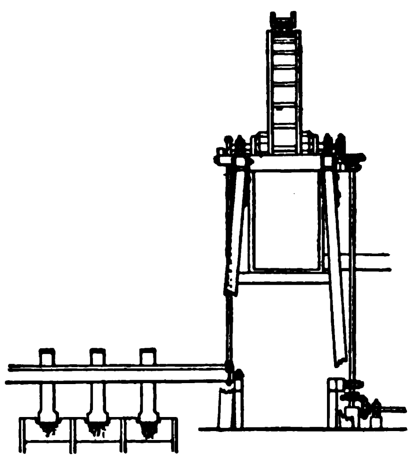


A trunking machine is shown in Figs. 6001, 6002. When the trunks are full, which generally occupies thirty-six hours, their contents are wheeled to a strake, or inclined wooden box, precisely similar to the one at the head of the square buddle, Figs. 5995, 5996. Here, as in the

6001.



6002.

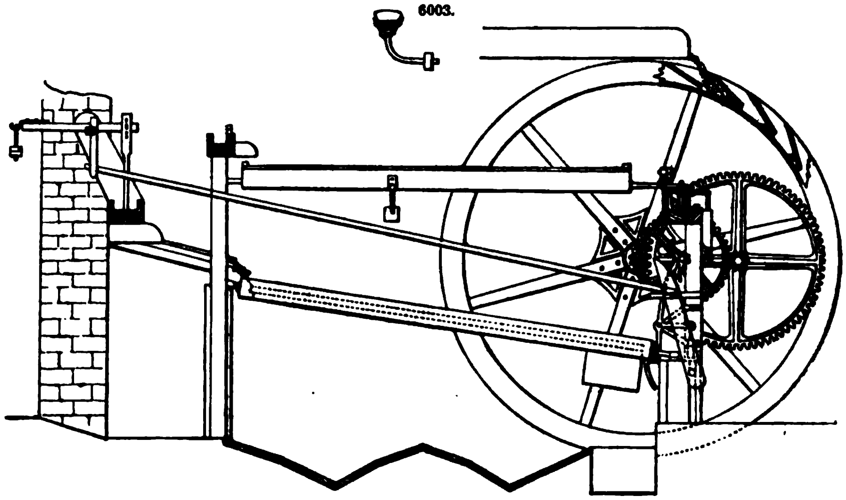


buddling operation, a stream of water is admitted; only, in this instance the water supplied flows from the head of the slime-pits, and the stuff, after being stirred with a shovel, is carried by the stream to the frames.

There are two descriptions of frame, one worked by machinery, the other by hand, but both are on the same principle. The machine-frame, Figs. 6003 to 6005, consists of an inclined table, about 8 ft. long and 5 ft. wide, with sides about 5 in. high. At both ends of the frame are fixed two round projecting irons, by which it hangs upon two upright pieces of timber, so that the frame may be turned perpendicularly, as in the hand-frame, Fig. 6006. As the table is inclined, it is necessary that the upright posts on which it turns should be fixed on each side of the centre of the frame, so that when in a perpendicular position the top side may be level. At the head of the frame is a board, Fig. 6004, on which a number of small diamond-shaped pieces of wood are fixed. These spread the liquid tin stuff over the whole width of the frame. After leaving the frame-head, the tin stuff falls on a sloping board, which can be turned up by means of a leather hinge at each end, when the frame assumes an upright position. At one side of the tail end of the frame, and attached to it, is a box, into which most of the water, after depositing its tin, flows. The mode of operation with the machine-frame is as follows;—The liquid tin stuff is admitted on to the frame-head in a small stream, and flowing on to the table in a thin film, over its whole length and breadth, deposits its tin according to its specific gravity, the heaviest, or best quality, being near the head, the second occupying the middle, and the worst the tail end of the frame. The water-wheel turns, with a very slow motion, a horizontal arm, or axle, on which are fixed, at the requisite distances, several tongues, intended, as the axle revolves, to disengage at the proper moment some part of the machinery immediately connected with the frame. Thus, the first tongue presses against the wooden rod running by the side of the frame, Fig. 6005, and stops the flow of the tin stuff. The next tongue then disengages a catch beneath the box containing the water, which has been running into it from the frame, and the table, or frame, at once turns, as shown by the dotted lines, Fig. 6003, striking against a catch, which frees the launder containing pure water, above the frame, and

which falling over, empties itself to the frame, washing the tin that is on it into two covers underneath. The table, or frame, then resumes its original position, the tin stuff is again admitted, the

6003.



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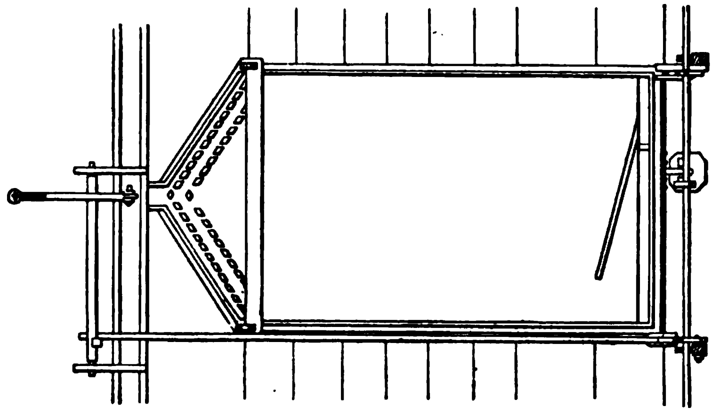
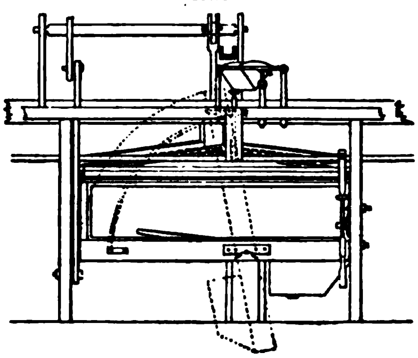


water again flows into the balance-box at the corner, and the table is again turned as before. The tin stuff from the two covers underneath the machine-frames flows into separate pits, each 12 ft. long, 5 ft. wide, and 1 ft. 8 in. deep; the cover near the head of the frame of course supplying the best quality. The refuse flowing off the ends of the frames, and from the balance-boxes, is thrown away. The contents of the head cover are now sent to the hand-frames; the stuff from the second cover being returned again to the machine-frames, and framed again.

6005.



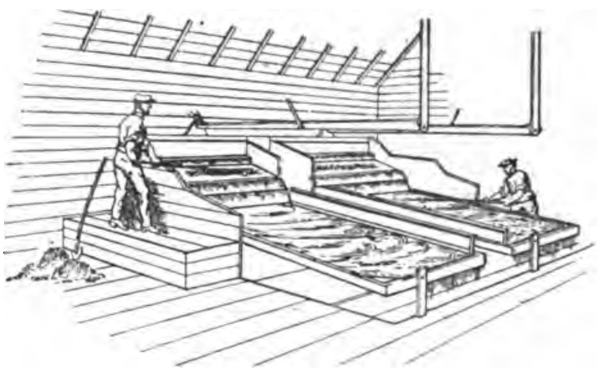
The Hand-frame, Figs. 6006, 6007, is on the same principle as the machine-frame, but it is worked by hand. The attendant on the frame has a wooden toothless rake, with which the tin stuff at the frame-head is jagged, and spread evenly over the frame. It will be observed that there is no balance-box in the hand-frame, but when it is desired to turn the frame the edge is pressed with the foot or the rake. The attendant then turns over the launder of water above, washing the tin stuff into two covers, as previously described in connection with the machine-frames. At the tail end of the frame an opening is left the whole width of the frame, to allow the refuse to run off, Fig. 6007; but as this perhaps contains some little tin it is preserved. The contents of the two covers flow into two pits, each 9 ft. long by 3 ft. wide. The tin stuff from the best cover, or pit, is

taken out, tossed, packed, and carried to the burning house. That from the second pit is framed again in the hand-frames. The catchers containing the refuse are connected with a slime-pit, into which the latter flows, where it undergoes the operation of trunking.

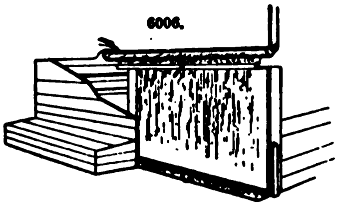
These operations are often varied in different mines, according to the nature of the ore; but the principle is everywhere the same, being the separation, by specific gravity, of the peroxide of tin from its matrix in the lode.

Most of the tin ores in Cornwall have to be roasted, or calcined, before they are fit for the smelting

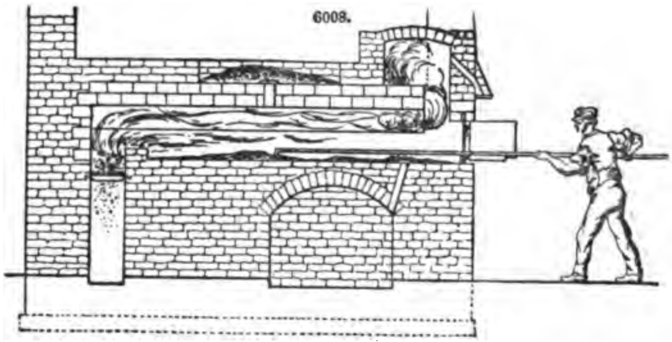
6007.



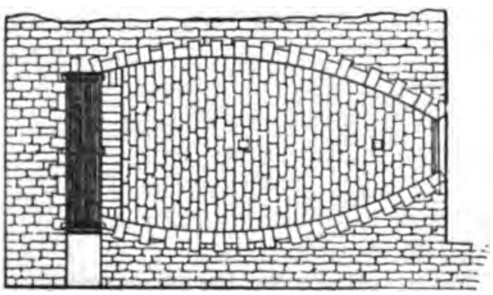
6006.



6008.

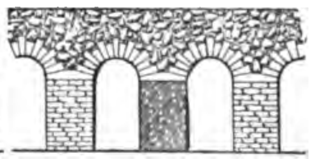


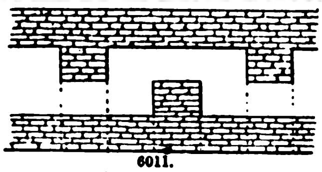
6009.



6012.

6010.





6011.

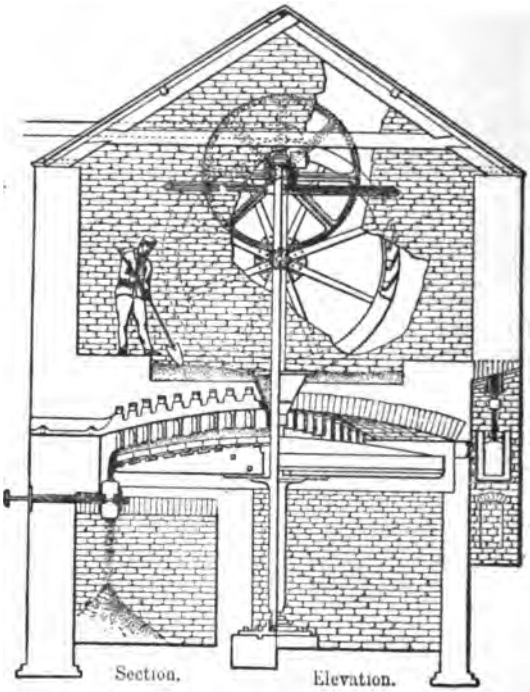
Arsenic Flues.

house, although in some mines the admixture with other minerals is so trifling that this operation is considered unnecessary. The furnace, Figs. 6008 to 6012, in which the roasting is carried on, is about 10 ft. long, 5 ft. 6 in. wide in the middle, and 3 ft. wide near the mouth, Fig. 6009. The fire-place, it will be observed, is situated at the back, the flames playing through the oven, and ascending the chimney, which is above the furnace-door. The ore, before it is submitted to the action of the fire, is thoroughly dried, in a circular pit, placed immediately above the oven, into which it is let down through the opening, when it is considered to be ready for calcining Beneath the oven, and connected with it by an opening, through which the ore, when sufficiently roasted, is made to pass, is an arched opening, about 4 ft. wide, termed the wrinkle. Here the ore is collected whilst another charge is being placed in the furnace. About 7 cwt. or 8 cwt. of ore is the quantity usually roasted at one time. Whilst undergoing this operation, dense fumes of arsenic and sulphur escape with the smoke from the fire, and pass through large flues, divided into several chambers. Figs. 6010 to 6012, where the former is collected. The flue is often 70 yds. long, and the greatest deposit of arsenic takes place at about 15 yds. from the oven, or furnace. Instead of being at once completely roasted, the whits from the stamps are sometimes first rag, or partially burnt for about

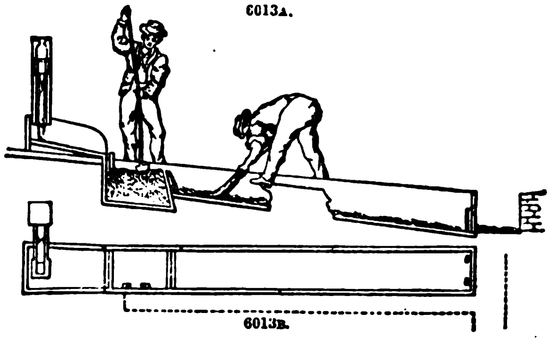
six or eight hours. The object of this partial burning is to save time and expense, nearly three-fourths of it being thrown away, after dressing it from the first burning.

Brunton's calciner, Fig. 6013, for calcining tin ore, is used in Cornwall. It consists of a revolving circular table, usually 8 ft. or 10 ft. in diameter, turned by a water-wheel, which receives through the hopper the tin stuff to be roasted, or calcined. The frame of the table is made of cast iron, with bands or rings of wrought iron, on which rest the fire-bricks composing the surface of the table. The flames from each of the two fire-places pass over the ore as it lies on the table, which slowly revolves, at the rate of about once in every quarter of an hour. In the top of the dome, over the table, are fixed three cast-iron frames, called the spider, from which depend numerous iron coulters, or teeth, which stir up the tin stuff, as it is carried round under them. The coulters on one of the arms of the spider are fixed obliquely, so as to turn the ore downwards from one to the other—the last one at the circumference of the table, projecting the ore, by this time fully calcined, over the edge, into one of the two wrinkles beneath. A simple apparatus called the butterfly, moved by a handle outside the building, diverts the stream of roasted tin stuff, as it falls from the table, either into one or the other, as may be required.

6013



6013A.



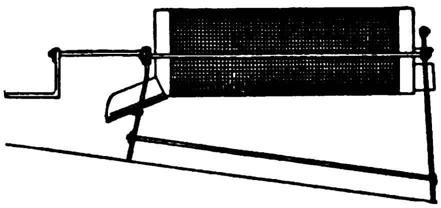
As soon as the roasted ore is removed from the wrinkle, it is cooled by wetting it with water. It is then buddled twice over, and the head tossed and packed. The other two middle heads are buddled separately, as many times as may be necessary, and tossed and packed as before. The tail is shaked, or washed, in a washing trunk, or tye, Figs. 6013A, 6013B, which is a long, narrow box, similar in appearance to a strip. The ore being placed near the head, and a stream of water admitted, is washed into the tye; it is violently agitated with a short broom, held in both hands. The stuff from the covers of the washing trunk is again passed through the stamps; whilst the light particles are again buddled, or framed, as many times as may be necessary. The bottom of the kieve, after tossing, is taken to the burning house again, and roasted for six or twelve hours. It is then buddled again twice, and the head tossed or chimmed as often as may be considered necessary to clean it. Chimming differs only from tossing in placing the kieve, in which the operation is carried on, on its edge, or chime. A livelier motion is thereby acquired, when the kieve is struck in packing, and by this means more of the stubborn concomitants are removed than would be the case in tossing when the kieve stands on its base. The skimpings, or top of the contents of the kieve after the first tossing, are buddled twice with a very gentle stream of water, and as the tin is fine, are afterwards tossed instead of chimmed; the latter operation being reserved for the tin of rougher quality. The tin stuff from the second tossing is burnt again and buddled as before; then chimmed and tossed, and at last becomes fit for the smelting house. In this condition it is sold to the smelters as black tin. The tails of the buddle from the second burning are taken to the shaking trunk, then tyed and dillued.

Dilluing.—This operation consists in placing in a close hair-bottomed sieve, without handles, some of the ore. The operator then immerses the sieve containing the ore in a kieve of water, and moving it round and from side to side, until the light particles are suspended in the water, dexterously inclines the sieve to one side, permitting the light portions to escape, when they subside at the bottom of the kieve. They are termed dilluing smalls, and are subsequently buddled as often as may be requisite. The remainder passes again through the stamps, mixed with fresh ore, again to undergo the processes we have described.

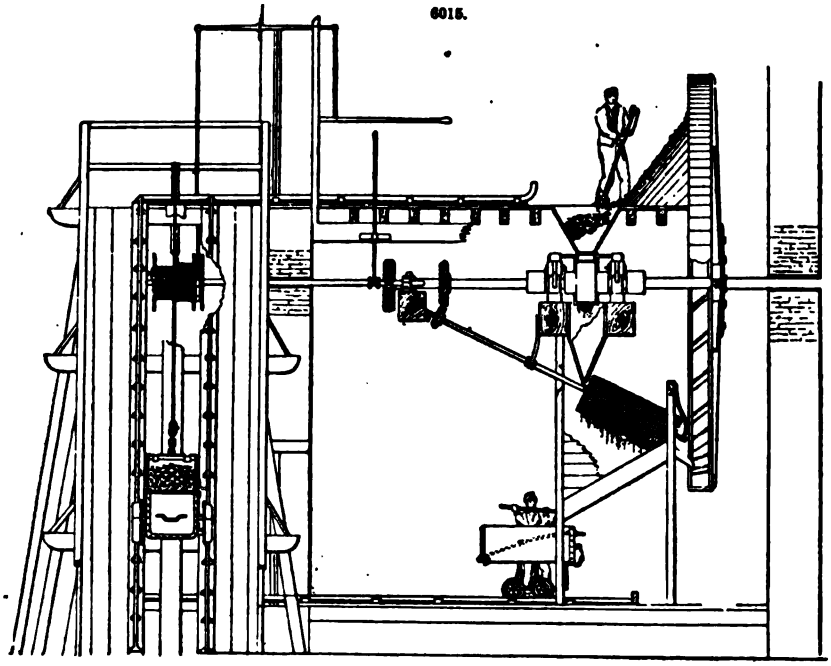
Dressing Copper Ore.—The ore, when brought to the surface, is usually conveyed from the mouth of the shaft in iron tram-wagons to the slides.

After the ore is thrown from the wagon into the slides, the larger stones are ragged, or broken into smaller pieces, with sledges of about 12 lbs. These are again reduced in size with hammers weighing about 3 lbs. The smaller-sized ore in the slides is riddled, either in a common sieve, or by means of a revolving griddle, Fig. 6014, the ore being thrown

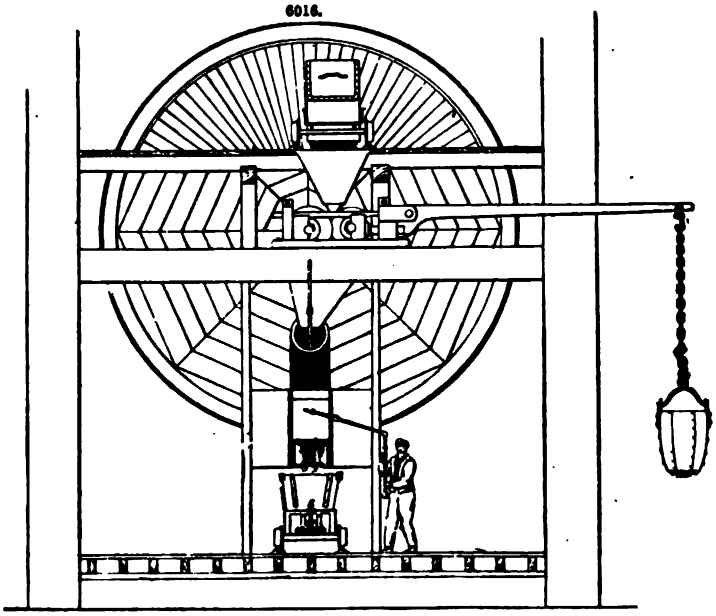
6014.



6015.



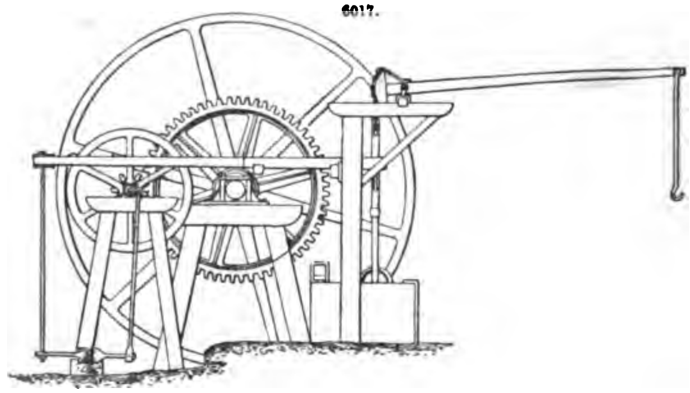
6016.



into the higher end whilst the griddle is turned round by the handle. The meshes of the sieve, or griddle, vary from ⅜ in. to 1 in. square, according to the quality of the ore. The whole is now divided into three portions—Prills, or pieces of pure ore; dradge, or second quality ore, where the metal is disseminated through the stone; halvans, or leavings. The prills are fractured in the crusher, Figs. 6015, 6016, which consists of the rolls, two cast-iron cylinders, about 2 ft. in diameter and 10 in. in width, placed almost touching, and which are made to revolve in opposite directions, the necessary motion being given either by a steam-engine or by a water-wheel. In Figs. 6015, 6016, which represent the original machine at the North Wheal Bassett Mine, the wagon containing the ore to be crushed is shown being drawn up an inclined plane. When it reaches the upper floor, the hauling machinery is thrown out of gear, and the wagon is emptied into the hopper immediately over the rolls. The empty wagon is then permitted to descend the incline by its own gravity, checked, if necessary, by the brake-handle.

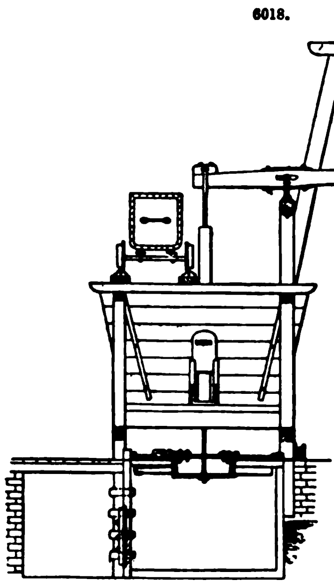
The ore, after passing between the rolls, one of which works horizontally on a side, and is kept close up to the other by means of two levers, with heavy weights attached to each, falls in a crushed state into the revolving griddle. The finer particles pass through into the wagon beneath, whilst any stones that will not go through the meshes of the griddle fall into the raff-wheel, which moves continually round, and conveys them to the upper floor, again to pass between the rolls. The crushed prills are then marketable, and are at once taken to pile, or to the heap of ore intended for sale. The dradge ore, or second quality, if containing much foreign mineral, must be cobbed and picked, or broken with a peculiar-shaped hammer. If tolerably free from iron pyrites, it is crushed, or bucked, and then jigged; an operation to which the smalls, after being griddled through a finer sieve than the one first employed, are also submitted, if not then found to be of sufficiently good quality to go to pile.

6017.

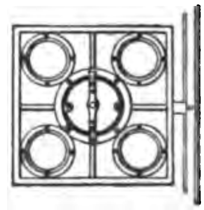


Jigging is an operation of importance in dressing copper ore. A sufficient quantity of the ore to be jigged is placed in a sieve, either copper-bottomed with fine holes, or in one having four or five holes to the square inch, a layer of iron pyrites having been previously thinly spread over the bottom. A peculiar vibratory motion is then given to the sieve, immersed in water. By this process the heaviest portion of the ore settles to the bottom of the sieve. That which passes through, and falls into the hutch, is usually fit for sale, as also the heavier part above referred to. It is now generally performed by machinery, and the sieve, which is usually of an oblong shape, is either moved by a brake-staff with the hand, or the same motion is given to it by a revolving axle worked by a steam-engine, as in Fig. 6017. Figs. 6018, 6019, represent a jigging machine, called Petherick's separator. The sieves containing the ores to be cleaned are placed in suitable apertures in the fixed cover of a vessel filled with water, connected with which is a plunger or piston, working loosely in a cylinder. The motion of the plunger causes the water to rise and fall alternately in the sieves, and effects the required separation, but in a more complete manner than can

6018.



6019.



be performed by jigging. The variety in the extent and quickness of the motion required for the treatment of different descriptions of ores is easily produced by a simple arrangement of the machinery.

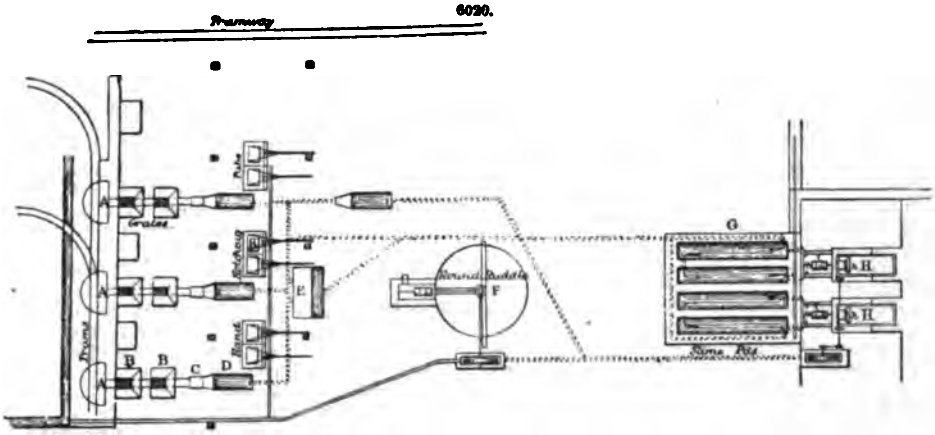
Dressing Lead Ores.—The following description of works erected and machinery employed by Thomas Sopwith, jun., at Linares, in Spain, shows a considerable advance upon the methods and machinery usually employed. The mine stuff, as extracted from lead mines, contains from 5 to 25 per cent. of galena. Pure galena, or sulphuret of lead, which is the ore of lead most commonly found, has a specific gravity of 7·75, and contains 86 per cent. of metallic lead. The lead ores of commerce are usually dressed to a tenor of from 74 per cent. to 78 per cent. If argentiferous, they are generally delivered with a lower percentage; because, on account of their greater value, it is not desirable to risk loss in successive processes of concentration; and because argentiferous ores are invariably more intimately associated with mineral impurities, difficult of separation, than ordinary lead ores. In England argentiferous ores are understood to be those which contain more than 12 oz. of silver in each ton of lead. The best and purest lead is, as a rule, obtained from the ores which contain least silver. No galena is found without more or less silver, and the richest in Great Britain is that of Cornwall, which contains commonly from 30 oz. to 40 oz. of silver to the ton. The separation of this silver from the lead does not come within the range of dressing operations, being effected by a subsequent process to that of smelting.

In dressing, all the applications of machinery act on the principle of separating, by means of their readier gravitation, the heavier particles of lead from the lighter ones with which they are associated. This is easy when the stuff treated consists of ore and fluor-spar, calc-spar, quartz, or any other impurity of much less specific gravity; but it becomes difficult when the ores are intimately blended with iron, copper, zinc, or other minerals having a specific gravity little inferior to that of galena; and still more so when such substances are also of marketable value, and where from the mine stuff several marketable products are to be obtained.

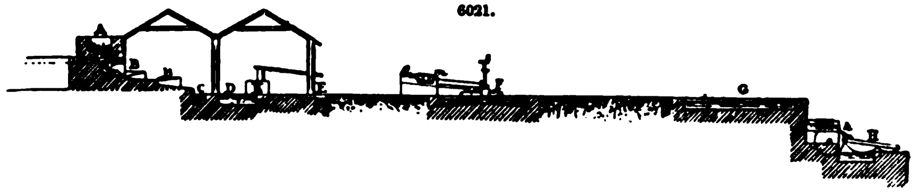
In his paper, Minutes Inst. C. E., vol. xxx., Sopwith made frequent allusion to the amount of work which can be passed through different apparatus. As this varies according to the nature of the stuff treated, and particularly as it is more or less rich, some standard, as representing ordinary average mine stuff, must be adopted. This Sopwith fixes at about 12 per cent. by weight of ore, of mine stuff, or of bouse treated, being equal to what in the north of England would be called worth 2½ bings a shift, a shift being eight wagons of a size in general use there, carrying of such work a load of about 1 ton each, and a bing being a measure weighing 8 cwt.

At the Linares Works about 350 tons of lead ore are produced monthly. There are two distinct dressing floors, the higher and the lower. On the higher floors, Figs. 6020, 6021, the mine stuff is first

6020.



6021.



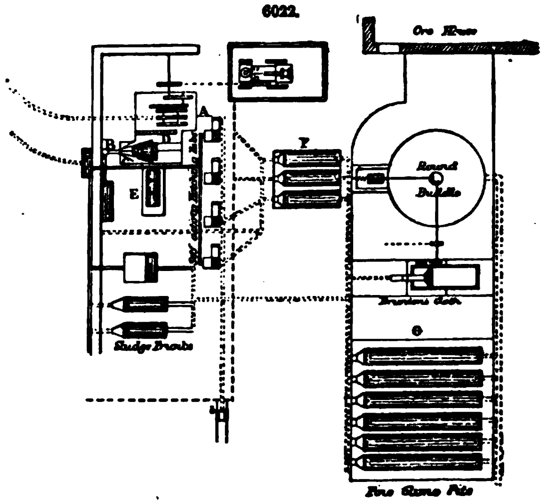
treated, and such separation as can be effected without the need of crushing is made: on these manual labour is principally employed. The stuff is separated into clean ore, waste, and a third class, where the ore and the waste are united in the same pieces, and which must be reduced to a smaller size, by means of crushing, or breaking, before they can be separated On the lower floors, Figs. 6022, 6023, is treated the stuff which passes through the crushing mill.

Figs. 6020, 6021, show, in plan and section, the arrangement of the higher floors, on which from 200 tons to 220 tons of lead ore are produced a month. The mine stuff drawn from the different

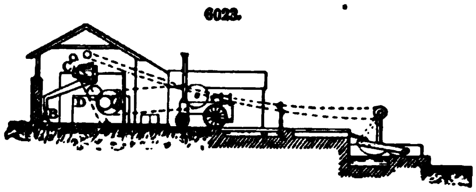
galleries of the mine is delivered into wagons at the shaft top, which convey it by a tramway to the teams A. By preference mine stuff of similar nature will be kept together in the same teams.

The washing operations on the higher floor commence by turning a stream of water into the teams A. The first separation is made at grate B, which is of cast iron 8 ft. long and 2 ft. broad, with horizontal spaces 1 in. wide. As a rule one grate only is employed, with spaces ⅜ in. wide; but Sopwith has found advantage and economy in using two, thus providing more grate surface for the pickers, one as described, and the other of similar size placed inferior to it, with spaces of ½ in. each. The sides of the grates are planes, sloping inwards; they are of wood covered with sheet iron, ¼ in. thick. On them the operation of picking is performed; a man stands at the top of the grate, and rakes stuff from the team into it; the small stuff goes through at once, and what remains is picked into the three classes already mentioned, and is at once conveyed in wheelbarrows or wagons to their destinations. Water is employed to facilitate the raking out, to carry the small stuff onward until it is deposited in the trunk D at the bottom of the second grate, and to clean the larger stones left on the grate, so as to simplify the operation of hand-picking.

6022.



6023.



The stuff which passes through the second grate is of a size convenient for hotching or jigging. In England from 25 tons to 30 tons is a fair day's work to pass over one grate. It has been found that the double grate used in the works described is capable of dressing about 40 tons of mine stuff or bouse a day.

Between the lower grate and the sludge-trunk is the stirring trunk C, into which all the stuff enters which passes through the lower grate. Here, with a roller fixed at the lower end as a fulcrum, the stuff is agitated with a shovel, to expose it as much as possible to the current of water, so as to relieve it of any particles of sludge, which would greatly impede the action of hotching, and when clean it is taken out and placed alongside the hotching tubs, the smaller particles or sludge being carried over into the sludge-trunk.

The common hotching or jigging tub or sieve K, which we have described at page 2536, consists of a plain rectangular tub, nearly filled with water, in which works a rectangular sieve with close sides and an open wire bottom. The hotchings, or the stuff to be hotched, are filled into the sieve to a depth of about 8 in. It is then hotched for about a minute, more or less, according to the richness and nature of the stuff. The long end of the lever is next depressed, held by a catch, and the sieve thus raised out of the water. The top part of the stuff contained in it is then skimped off with a flat piece of sheet iron, held by both hands, into a wheelbarrow or wagon, as waste. More stuff is now filled in, and the same operation is repeated until the sieve is nearly full, when, besides cleaning off the waste, the matter next to it, called technically chatts, consisting of particles with lead and some impurity united, is also separated, and afterwards the pure ore is found nearest to the bottom, ready for delivery into the ore stores.

One hotching tub can treat from 8 tons to 15 tons of stuff a day, allowing for stops for taking out smiddum, rich ore.

To render the chatts marketable, further subdivision is necessary, and on most washing floors a separate crushing mill, adapted for fine crushing, is provided.

At the bottom of the hotching tubs, the ore which passes through the coarse wire bottom of the sieve accumulates; this is called smiddum, and generally contains upwards of 40 per cent. of lead, and is often nearly pure. To enrich it the buddle E is used. This is a plane slightly inclined, made of either wood or of iron, and about 6 ft. wide by 5 ft. long. A stream of water is let in at the top, and the smiddum is drawn gradually in small quantities across it, the operation being repeated until all the light particles have been carried away.

The sludge deposited in the sludge-trunk D, Figs. 6020, 6021, is emptied about twice a day, and is removed to the round buddle F. It is filled into the apparatus at *g*, where it is well broken up with knives fixed on a revolving axle. Water is also admitted, and with the sludge passes through a rotating cylindrical wire-work sieve, of 10 to 15 holes a lineal inch, which separates and delivers apart at *m* any chance piece of stone or lumps of sludge insufficiently broken up, chips of wood, and in Spain the bits of esparto grass proceeding from the common use underground of esparto-grass baskets for conveying the ores, and from the sandals worn by the miners, which are

made of the same material. The work which passes through this sieve is conveyed by the water to the centre of the round buddle in a launder, for which an inclination of 1 in 10 is sufficient.

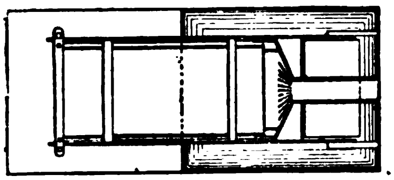
The following modifications in the form of buddle usually employed in England have been introduced. The diameter has been increased from 18 ft. to 21 ft., and the centre, usually a tapered cone about 12 in. at the bottom and 6 in. at the top, is a plain cylinder 2 ft. in diameter; and in place of two revolving arms with suspended cloths sweeping along the top of the stuff being dressed, making three to four revolutions, two revolving sprays are employed, making seventeen revolutions a minute. In the sprays clean water is used, delivered by a small launder into a funnel on the upright axle.

Of the stuff delivered at the centre the heaviest particles are first deposited, the operation going on until the buddle is full to a depth of about 20 in., when the water is drained off. The stuff at the inner part, to a distance of 4 ft. from the centre, called the heads, will be found enriched from say 12 per cent. to about 40 per cent.; this is separated. The next lot, containing about 12 per cent., is also separated for re-treatment with the next parcel of work from the sludge-trunk, and the stuff at the outer circumference is wheeled away as waste, none of it probably containing more than 1 per cent. of ore. The heads, on a sufficient accumulation, are treated similarly, and can be enriched by a second operation so as to produce from 70 per cent. to 74 per cent. If the sludge presents difficulty for separation the operation would be repeated a third time.

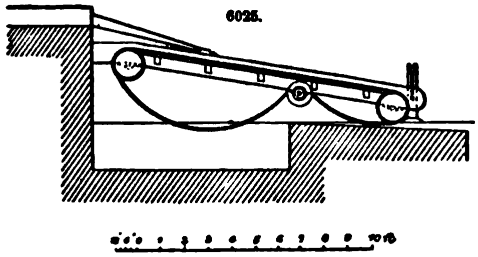
The diameter of the buddle is 21 ft. The diameter of the centre, 2 ft. Number of revolutions of sprays, 17 a minute. Number of revolutions of sieve, 17 a minute. Number of tons treated, 8 tons to 10 tons an hour. Inclination of bottom, 1 in 10. The bottom is made of cement in preference to wood. The buddle is turned by a small water-wheel of about ½ H.P.

The water which passes away from the sludge-trunk and the plain buddle, and also from the hotching tubs, when they are emptied, contains fine slime and ore in suspension, and is conveyed by drains to the slime-pits, which are shown at G. The slimes are treated in a machine called the Brunton's cloth, shown at H, and in detail, Figs. 6024, 6025. The cloth, which is of coarse canvas

6024.



6025.



stiffened with paint, is strengthened and kept level across the face by laths of elm a few inches apart. It is held in a frame which is inclined about 1 in 6, the inclination being adjusted by suspending screws at the bottom, and passes over rollers fixed at the top and the bottom of the frame. The cloth moves upwards at a rate of about 15 ft. a minute. The slimes are well broken up amongst water, and ore delivered on to the cloth at *h*, Figs. 6020, 6021. A stream of clear water at *i* has sufficient force on the inclined surface of the cloth to carry away the light particles; the greater adhesion of the grains of ore enabling them to withstand it, and remain attached to the cloth, until dipped into the tank below, when they fall to the bottom.

There are therefore three adjustments for treating different natures of stuff, namely, inclination of the cloth frame, rate of movement, and quantity of clear water admitted. The apparatus as generally used is fairly efficient, and its efficiency is increased by the addition of a slight percussion motion in many of the German washing floors.

The first time of treatment in this machine suffices to enrich the stuff treated to about 45 per cent., the waste matter being carried away from the tail of the apparatus.

The enriched slimes of 45 per cent. are passed through the dolly tub—a cylindrical tub, about 3 ft. in diameter at the top, and 3 ft. deep, tapering towards the bottom, and nearly filled with water. The stuff as thrown in is kept agitated by revolving a fan inside, and when a sufficient quantity has been introduced, it is allowed to settle, during which time the sides of the tub are knocked with wooden logs or hammers, giving a vibratory motion to the water, and tending to keep the particles apart, and prevent their adhesion in knobs. Slimes can be enriched to about 70 per cent. by this means.

The form of crushing mill in general use in England, Fig. 6026, is worked generally by steam or water power. The mineral crushed is passed to the hotching tubs, and is subsequently treated much in the same manner as on the higher floors, with this difference, that in many cases advantage is taken of the motive power required for driving the mill to attach a shaft from which to work the hotching sieves. The work to be crushed is delivered into the hopper *a*, passes through the rollers *b*, *b*, which are kept in contact by the pressure of a heavy lever *c*, loaded at one end, and falls into *d*, a cylindrical rotating sieve, inclined about 1 in 8, covered with coarse wirework, which allows the mineral, when sufficiently crushed, to pass through, returning larger particles to the raff-wheel *e*, which elevates them to a shoot, conveying them to the hopper *a* again. The whole of the crushed material is passed through a stirring trunk, making a partial separation of the sludge previous to its being treated in the hotching tubs.

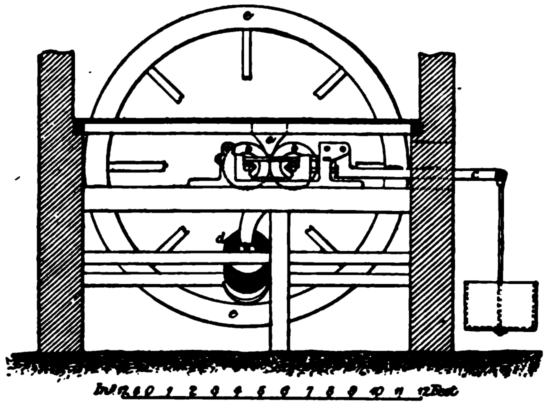
A strong building is required, owing to the height at which the rollers are placed above the ground, and from the strain caused by the heavy weight suspended from the lever, frequently about 15 cwt. to 20 cwt. suspended at a distance of 9 ft. to 10 ft. from the fulcrum, which is in continual and violent motion when the mill is at work.

In the lower, or crushing mill, floors, next to be described, and which were erected some time after the higher floors already alluded to, an attempt has been made to secure continuous treatment for the ores.

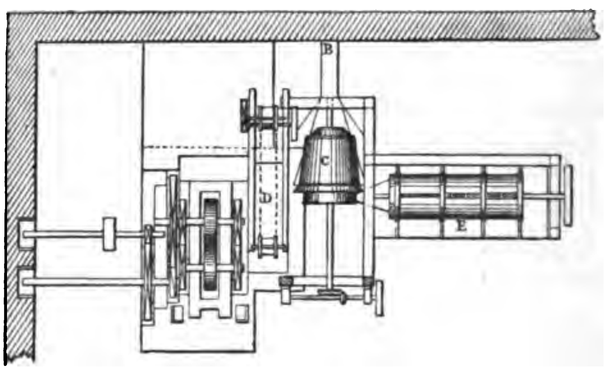
The mine stuff which requires crushing is here treated. To become fit for the crushing mill, it is reduced to a size which would allow it to pass through a 5-in. ring.

The general arrangement of the crushing-mill dressing floors is shown in Figs. 6022, 6023, and 6027 to 6029. The stuff to be crushed is conveyed by wagons, and emptied into the hopper *a* of the crushing mill. When crushed, it is elevated by D, an endless link-chain with buckets, called the Jacob's ladder, and delivered into a classifying trommel C, which returns to the crushing mill all the particles which are too large for the hotching machines, separates all the sludge which is considered too small for hotching, and delivers in another direction the material of proper size and condition for machine hotching.

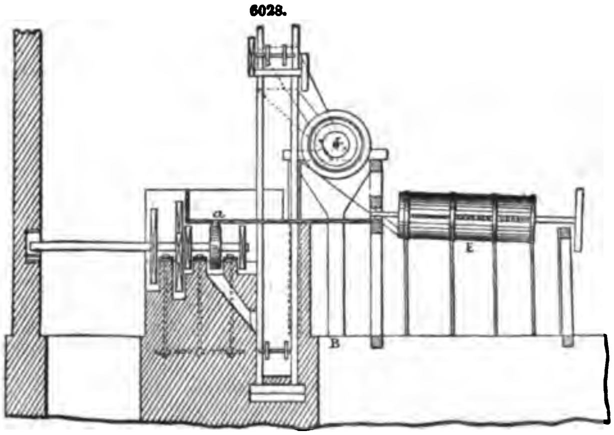
6026.



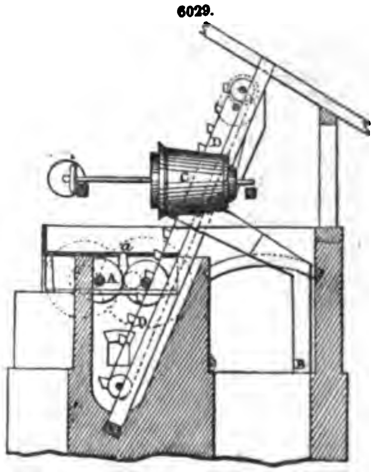
6027.



6028.



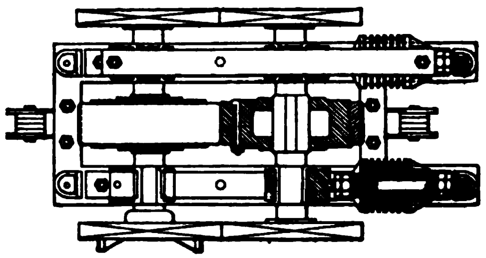
6029.



The crushing mill, Figs. 6030 to 6032, is compact, and any degree of compression can be given to the rollers by means of the caoutchouc buffers, which are equally effective as heavy weights and levers. The rolling surface is of chilled iron, made as a ring, which is kept on the roller-shaft by three wedge-bolts. The diameter of the rollers is 37 in., the breadth 10½ in., and they make eight revolutions a minute. The velocity of the rolling surface is therefore 77½ ft., and the crushing area of each roller is 68 sq. ft. a minute. This form of crushing mill is self-contained, requires scarcely any foundations, and absorbs less working power in friction than the form used in England; and the working parts are few, easily dismounted, and can

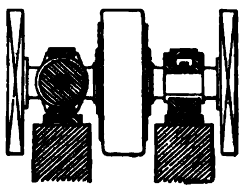
be readily manœuvred. The shafts carrying the rollers are geared with toothed wheels at each side. One roller, therefore, does not work by friction only, as in many mills. By being geared, a better grip is secured, and the action is altogether more steady and regular. The toothed wheels have teeth unusually long, so as to keep in gear when the rollers become separated by the passage of some large and hard stone, or other strain tending to separate them, which may be sufficiently powerful to overcome the compression of the india-rubber springs. With the rollers in fair order, from 5 tons to 6 tons an hour can be treated.

6030.

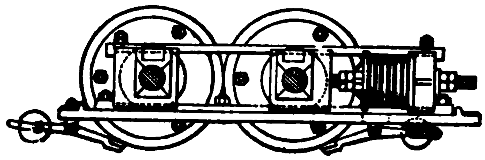


No difficulty has been experienced from the use of the caoutchouc springs, even during the summer, when working in a temperature of 90° in the shade. One set has lasted about two years, and with care should serve as long again.

6032.



6031.



The wear of the chilled rollers is very variable. Steel ones are occasionally used, and answer very well, and their use would doubtless become general but for the expense. From four to eight months is the general time of service, representing, say, 5000 tons to 10,000 tons of material crushed by the chilled rollers Sopwith used.

In considering the action and duty required of a hotching machine, it must be evident that the separation, by gravitation, of the several matters treated in such a machine must be greatly facilitated, when the particles are of uniform size, otherwise it is clear that a large piece, say, of iron pyrites, would gravitate more quickly than a small one of lead ore; for, whereas the weight increases as the cube, the surface opposed to the resistance offered by the water is only as the square of the side of particles of similar form. True, in the English system lead has been satisfactorily dressed without sizing; but it is principally because lead, for the most part, is raised from veins, where the accompanying impurities are of much less specific gravity. There would be no difficulty, either, in showing that even in those cases the dressing operations would be improved and performed more economically by the use of sizing apparatus, which is simple and efficient, and inexpensive both in first cost and future working. For the application of sizing to be efficient in the treatment of ordinary ores of lead, it is by no means necessary to employ such elaborate arrangements as are in use in Germany.

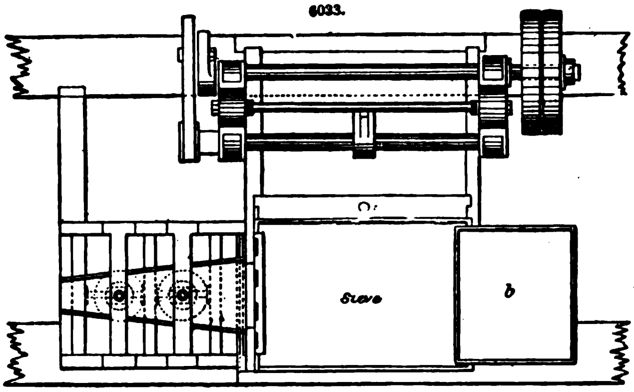
The number of classes adopted by Sopwith have given good results, and are as follows;—

Of the material crushed, all which will pass through a perforated plate with round holes of 1½ millimètre is treated in buddles. All particles which will not pass through a perforated plate with round holes 10 millimètres in diameter are returned to the crusher. All the material to be hotched, therefore, is clean shingle, which is separated into the following sizes;—

		Millimètres.		Millimètres.
No. 1,	which will not pass through holes	1½	in diameter, but will pass through	2½
„ 2,	„ „	2½	„ „	5
„ 3,	„ „	5	„ „	7
„ 4,	„ „	7	„ „	10

The classification is thus effected; the material having passed through the crushing rollers is raised by the Jacob's ladder, and delivered into the first trommel C, which is constructed of an outer shell of perforated iron with round holes 1½ millimètre diameter, and an inner shell of stronger iron with round holes of 10 millimètres diameter. A perforated pipe, parallel to the outer edge of the trommel, conveys jets of water to facilitate the separation. The work after entering progresses naturally onwards and downwards; the sludge passes through the inner and outer shells, and is conveyed in an iron launder to B, the particles insufficiently crushed arrive at the lower end of the trommel, and, dropping into the buckets fixed in the circumference of the inner trommel serving as a raff-wheel, are lifted up and delivered into a shoot with sufficient elevation to carry them to the hopper again. The largest quantity, however, goes by a second launder to the trommel E. supplied with water in a similar manner to the first one; an inclination of 1 in 15 is sufficient to give onward motion to the material being treated. It is equally divided into three classes, the first being covered with perforated plates, with holes 2½ millimètres in diameter, the second 5 millimètres in diameter, and the third 7½ millimètres in diameter and the stuff falls through one or other of these divisions,

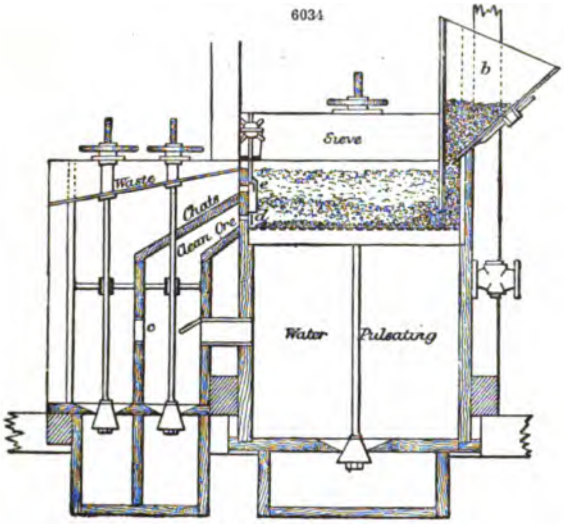
6033.



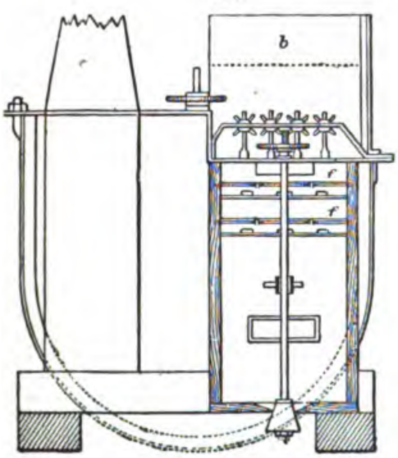
or is carried over the end to their respective compartments, whence it is taken to the hotching tubs, each tub being adapted for the size it is intended to treat.

The hotching machines employed, Figs. 6033 to 6039, are self-acting. Instead of the sieve moving, as in the common one, it is stationary, and the water is set in motion by a loosely-fitting piston *a*, Fig. 6036, which at each pulsation raises all the stuff in the sieve. The relative positions of the several particles naturally change at each stroke, the heaviest or purest particles of ore eventually being brought to occupy the bottom. The stuff, consisting of ores, waste, and chatts, is delivered into the hopper *b*; the bottom of the sieve is level, but the new stuff, falling from the hopper, gradually displaces that in the sieve, causing it to move forward. On reaching the end of the sieve, a distance of 28 in., a perfect separation is found to have taken place; the lighter particles are at the top, and at each pulsation of the machine some are carried over the shoot into

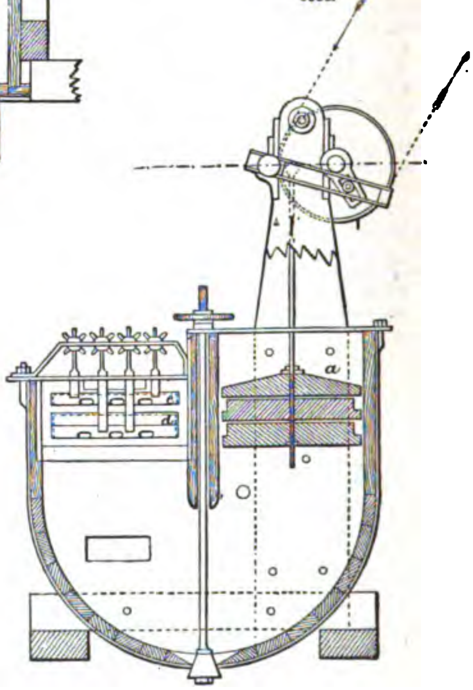
6034



6035.



6036.



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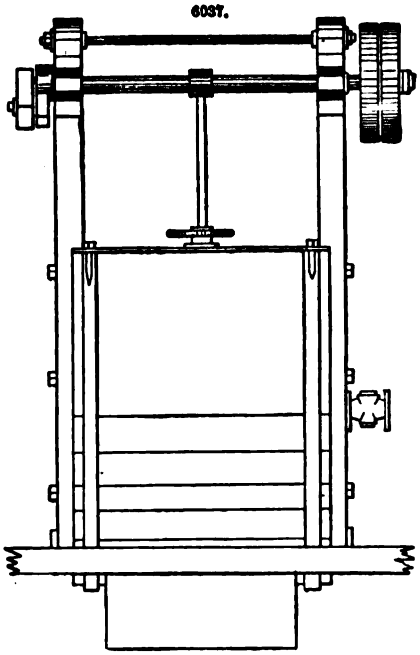
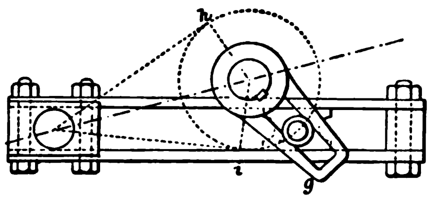
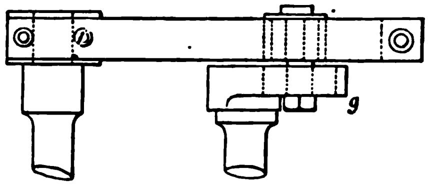


6038.





6039.

the waste launder. The heavy ore is at the bottom, a depth of $1\frac{1}{2}$ in. to 2 in. being generally occupied by it. Apertures properly regulated admit the ore into the cistern *c*; a broad flap of sheet iron *d*, Figs. 6034 to 6036, is regulated by the man in charge to such a distance from the bottom as is found to pass the ore only, and an upper flap *e* and apertures serve for the exit of the chatts. The size of the apertures is also regulated at will by means of a slider *f*, Fig. 6035, worked by a screw, which cuts off more or less of the holes as may be necessary. A fast and a loose pulley are attached to each hotcher. The ore and chatts are emptied from time to time from the cistern.

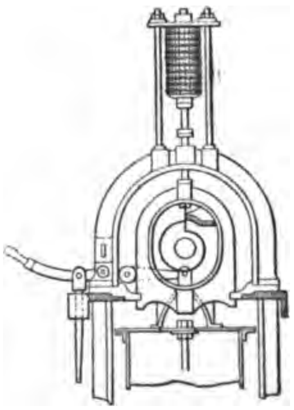
Formerly the piston was moved by an eccentric; the present motion is given by a crank *g*, Figs. 6038, 6039, of variable stroke working in a slot. The down stroke is given as the crank moves from *h* to *i*; and as the crank-pin revolves at a uniform rate, the down stroke, during which the stuff is lifted, is therefore quick, and the return stroke slow, allowing more time for the deposition of the particles. The stroke of the crank can be varied by moving the crank-pin up and down a slot, the pin being fixed by means of a nut behind.

From experiments with different hotching machines, it has been ascertained that the number of strokes a minute suitable for different sizes of work, can be advantageously increased for the larger particles, while the length of the stroke is found to be of less importance, although this also has been similarly increased.

The machine for washing No. 1 size has a stroke of 1 in., and makes 82 strokes a minute. No. 2 size, a stroke of $1\frac{5}{8}$ in., and 84 strokes a minute; No. 3 size, a stroke of 2 in., and 86 strokes a minute; No. 4 size, a stroke of $2\frac{3}{8}$ in., and 96 strokes a minute.

The machine for the finer stuff has a different movement, applicable more particularly to short strokes,—a revolving cam, as in Fig. 6040, with buffer-springs composed of well-prepared caoutchouc; its other details, as regards self-action, being similar to those already described.

6040.



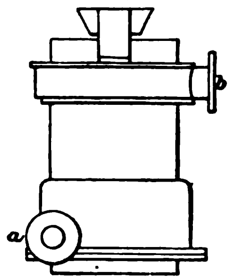
The waste from each of the tubs is conveyed by the water which overflows with it along the waste launder underground to *b*, Figs. 6022, 6023, and is there delivered into wagons, with perforated iron bottoms so as to allow the water to drain off, and wheeled over the waste heap.

The sludge which passes through the outer skin of the first trommel is delivered into a separator B, Figs. 6022, 6023, which consists of a cylinder with an annular space formed by the insertion of an inner block, regulated in diameter according to the size of the work it is intended to operate upon. This is shown in detail in Figs. 6041 to 6043. In this annular space a stream of water is constantly rising, brought by the supply-pipe *a*, of sufficient force to effect a separation, carrying the finer particles over the top into the launder *b*, whence it is conveyed away for treatment in the round buddle and the Brunton's cloth, whilst the coarse and richer particles fall to the bottom, and are treated in sludge-trunks, or ties, Fig. 6022, of simple construction. A stream of water distributed over the whole breadth of the tie is admitted; the sludge is filled in at the top with a shovel, being well distributed there, and exposed to the current of water, the heaviest particles settle first, and the lighter ones are subsequently removed; the heads resulting from the first operation are put aside, and subjected again to the same treatment. After being passed twice, or at the most, three times through the tie, they are fit for market.

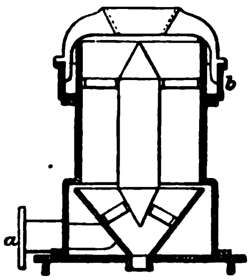
The other sludge which was carried upward in the separator is conveyed to the sludge-pits at F, Fig. 6022, and treated by the round buddle, while the finer portion which does not settle there is carried by the water into the slime-pits at G, where it is taken out, and treated by Brunton's cloth.

The machinery employed is worked by a 10 H.P. portable engine.

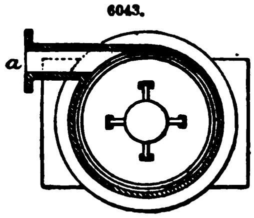
6041.



6042.



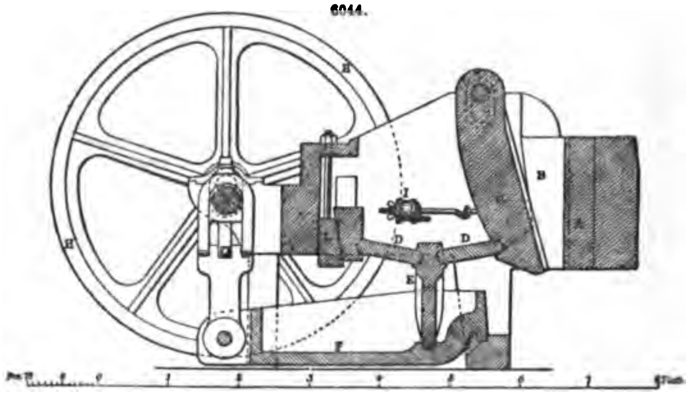
6043.



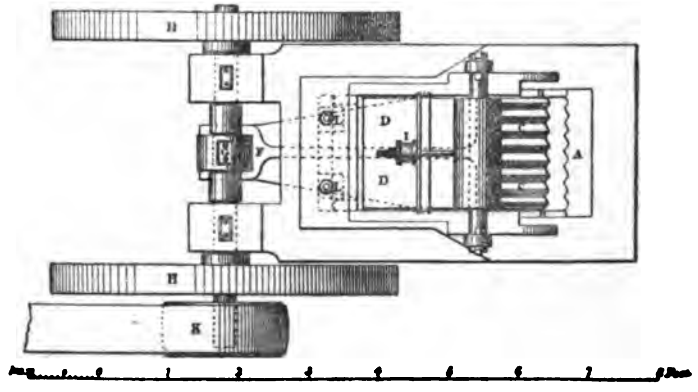
Blake's Stone-breaking Machine.—Figs. 6044 to 6048 are of this useful and ingenious machine as made in England by H. R. Marsden, Leeds. It is driven by steam power, and consists of a crushing hopper, in which the stone is broken between a pair of jaws, one fixed in the frame of the machine, and the other vibrating on a centre through a short distance, worked by a toggle-joint and long lever which receives its motion from a crank-shaft.

The fixed jaw A, Fig. 6044, against which the stone is crushed, is a vertical fluted block of cast iron, bedded in zinc in the end of the very strong cast-iron frame of the machine, and held in its place by loose tapered cheek-pieces B, B, which fit into recesses on each side of the hopper. The movable jaw C is fluted on the breaking face to correspond with the fixed jaw, the ridges of the movable jaw being opposite the grooves of the fixed jaw; and the movable jaw is suspended from a large transverse pin above the frame. At the back of the movable jaw, to give the motion, are two struts D, D, in the form of flat cast-iron plates extending the whole width of the jaw, and bearing in the middle in the upright thrust bar E; this bears at the bottom upon the

6044.

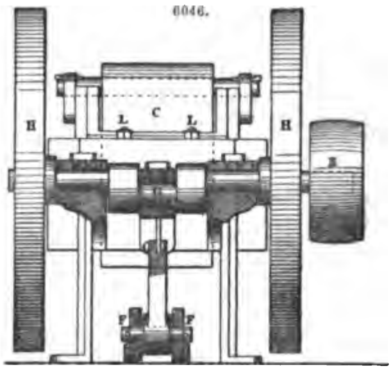


6045.



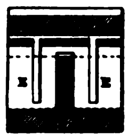
main lever F, the whole forming a horizontal toggle-joint of simple construction and great strength. Figs. 6044, 6047, show the thrust bar E of the toggle-joint; and Fig. 6048, is a plan of one of the strut-plates D. The main lever F, Fig. 6044, has its fulcrum on a cross beam cast in the frame of the machine, and when lifted by the connecting rod and crank G at the outer end it presses forward the breaking jaw C by straightening the toggle-joint. In the depression of the lever the jaw is drawn back ready for the next stroke by the india-rubber spring I.

6046.

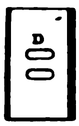


The entire frame of the machine is in one single casting, and has feet cast upon it to stand upon a brick or stone foundation; the feet have bolt-holes cast in them for the purpose of bolting the machine down to the foundation; in practice, however, it is found to require nothing besides its own weight, about 8 tons, to keep it steady in its place. It is fixed high enough to allow a railway wagon or a cart to be placed under the hopper to receive the broken material direct from the crushing jaws. The crank-shaft G carries a fly-wheel H on each side of the machine, and also the driving pulley K, which receives a belt from the steam-engine or shafting employed to drive the machine.

The movable jaw C, Fig. 6044, works on a round bar of iron, which passes loosely through it, and forms the centre upon which it vibrates. Every revolution of the crank causes the lower end of the movable jaw to advance towards the fixed jaw about $\frac{3}{8}$ in. and return, and when the jaw is drawn back, the stone in the hopper falls lower down to fill up the space caused by drawing back the jaw, and is then ready for the next bite of the jaws, and so on until the broken stone drops out at the bottom. The extent of motion of the crank end of the main lever F is $5\frac{1}{2}$ in., giving a total leverage of 14 to 1. The distance of the jaws apart at the bottom determines the size of the broken material, and can be altered at pleasure. A variation of $\frac{3}{8}$ in. can be made by raising or lowering the screws which adjust the wedges L, thereby altering the abutment for the toggle-joint. Further variations are made by changing the strut-plates D, and putting in longer or shorter ones, as may be required.



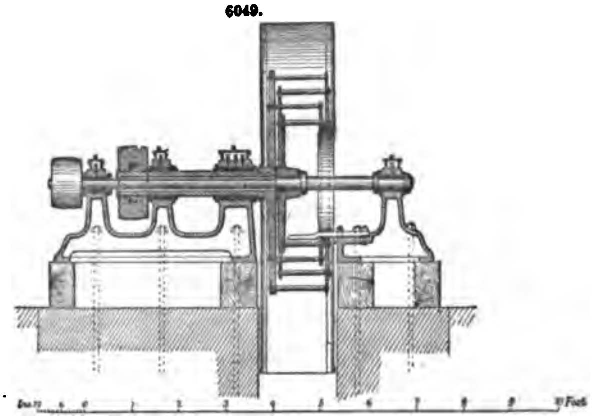
6047.



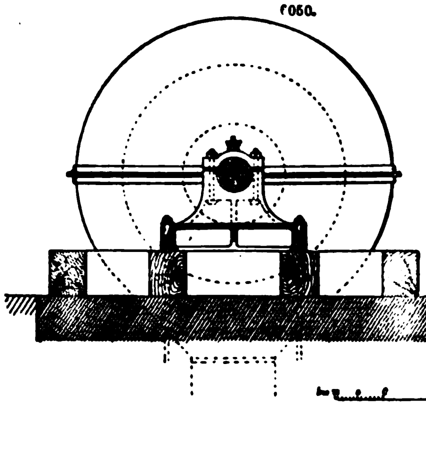
6048.

Thos. Carr's Mineral Disintegrator is shown in Figs. 6049 to 6051. It is made of great strength in the beaters, and small diameter, being $4\frac{1}{2}$ ft., and having four cages of beaters. The two discs are both carried from the same side of the machine, the shaft of the left-hand one being made

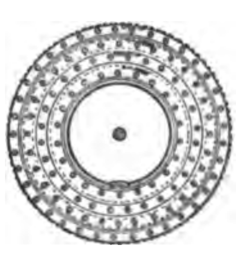
6049.



6050.



6051.



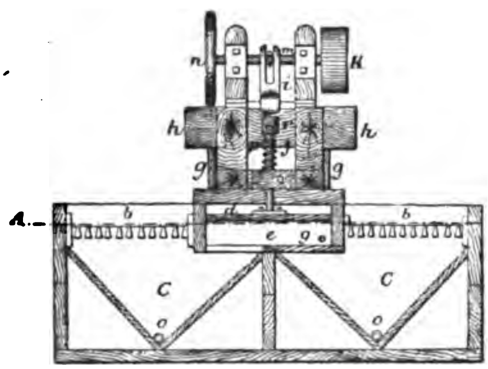
tubular, and that of the right-hand disc carried through it without touching it, as in Fig. 6049; by this arrangement the central opening through which the material is fed into the machine is left entirely unobstructed by the driving straps, and the material can be thrown into it by a shovel. The speed it is driven at varies from 350 to 500 revolutions a minute, according to the hardness of the material that is being pulverized, the degree of fineness to which it has to be reduced, and the driving power available.

When a soft and adhesive material is operated upon, a portion adheres to each beater, and the machine sometimes, though very rarely, requires cleaning after ten or twelve hours' working. As the material adheres only to the back surface of each bar, while the front remains clean, the machine is readily cleaned by running it backwards for a short time, where there is the means of reversing the driving power; or the cleaning is effected without reversing by throwing in while at full speed 1 or 2 cwt. of some brittle and dry material.

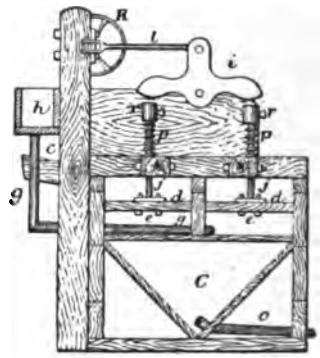
The 4½-ft. machine is capable of pulverizing 5 to 15 tons of material an hour, according to the nature of the materials and the degree of fineness to which they are reduced; the amount of power required to drive the machine, which varies with different materials, is from 10 to 25 horse-power. See Mills, p. 2488.

Dressing Silver Ore in Colorado.—The silver ore of the Comstock lode in Colorado is chiefly argentiferous galena, two or three varieties of blende, some argentiferous grey copper, some ruby silver, and other rich silver minerals.

6052.



6053.

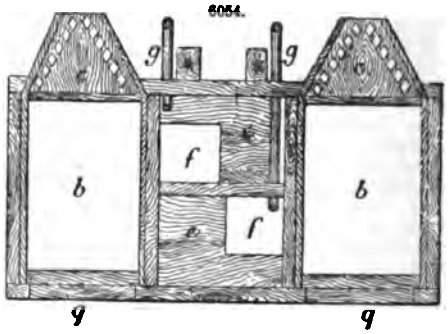


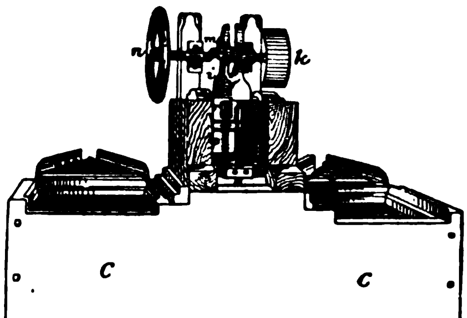
The concentrating machinery used for the preliminary dressing of the ore as a preparation for smelting comprises crushers, Cornish rollers, screens or appliances for sizing the material, and John Collom's ore-washing machine.

Figs. 6052 to 6055 show some of the details of the construction of this machine, or more correctly of two machines, which for convenience are put together as one, though quite independent of each other in their operation. Fig. 6052 is a longitudinal section; Fig. 6053, a transverse section; Fig. 6054, horizontal section on line A B; Fig. 6055, perspective view.

A double machine, like that shown in Figs. 6052, 6054, consists of a box or tank about 7 ft. long and between 3 and 4 ft. wide, divided by a middle partition into two parts. Each of these parts is fitted on the inside with inclined partitions sloping from the four sides toward the centre of the box, and thus forming two cisterns C, above each of which is placed a sieve *b*. The sieve frame may be furnished with a wire-cloth sieve of any desired degree of fineness, according to the character of the ore to be dressed. Between the two sieves are the piston or plunger compartments *e*, separated from each other, and each connecting by an aperture *f* with one of the cisterns C. Each aperture *f* affords communication to the cistern nearest to it, but without any connection with the other cistern. The plungers *d* move up and down in the compartment *e*, being forced rapidly downwards by the rockers *i* and lifted again by the action of springs *p*.

6054.





6055.

The rockers are set in motion by pulleys K, with which they are connected by eccentric-rods *l*. The cisterns and plunger compartments are supplied with water by pipes *g*, and when the outlets *o* are closed, the machines are filled with water, the overflow being at *q*, in front of the sieves. The movements, therefore, of the plungers, which follow each other in rapid succession, produce an agitation of the water, which rises through the sieves with a constantly throbbing motion. The crushed ores, consisting of heavy mineral and gangue, are brought upon the sieves *b* by a stream of water that enters through the distributing boards *c*, and, being subjected to the agitation caused by the plungers *d*, are held in a state of partial suspension, during which the heavier metallic particles sink, while the earthy matters rise to the top, and are carried off by the water at the overflow *q*. That portion of the metallic substance which is fine enough to pass the meshes of the sieve falls through into the hutch or cistern O, and may be withdrawn thence at stated intervals by the outlet-pipe *o*; while the coarse part remains upon the sieve, and is cleaned up from time to time, leaving a stratum on the sieve for continued operations. The thimbles *r*, on the plunger-rods *p*, serve to adjust the length of the stroke. The action of these machines is excellent. They effect the separation of the galena in a very thorough manner, not only from the earthy gangue, but from the lighter metallic minerals, such as the zincblende and grey copper. The last two are obtained together, owing to the similarity of their specific gravities, and they are also mingled with heavy spar and some quartz.

The general arrangement of this crushing and concentrating machinery is as follows;—The ore is brought upon the receiving floor, where the larger pieces are broken sufficiently to admit the fragments to the crusher. The clean pieces of galena and zincblende are also selected by hand as far as possible before the material is sent to the dressing machinery. After passing through the crushers the ore falls upon a screen furnished with a No. 6 sieve, that is, having six meshes to the lineal inch. Whatever passes over this screen without falling through must be still further reduced in size before going to the washing machines, and passes, therefore, from the screen to a set of Cornish rollers placed below. The material that falls through the sieve enters an elevator, and is raised to the sizing sieve that stands above the washers. The elevator also brings the material delivered from the rollers, still further reduced by them in size, to the same point The sizing sieve or screen consists of a frame ubcut 6 ft. long by 18 in. wide, slightly inclined from one end to the other. The upper end of the frame is fixed on a pivot, while to the lower end is attached a long arm and connecting rod, by means of which a revolving cam raises the lower end of the frame about 2 in., and lets it drop again upon a fixed support below. The movement is rapid enough to impart a constant jigging motion to the screen, and thus to assist the material upon it to slide down over its surface. The upper part of the screen is furnished with a No. 9 sieve, while the lower half has a No. 6. The material that passes through the first goes to the finer washing machines; that which falls through the second, to a coarser machine; while all that passes entirely over is returned to the rollers for finer crushing and a repetition of the process. The material then goes to the ore-washers. Two of the double machines, containing four sieves, stand on a raised floor sufficiently elevated above the other two that the material delivered from the outlet-pipes *o* of the first may flow to the sieves of the second. One of the upper machines, and one of the lower immediately in front of it, are furnished with No. 6 sieves for washing the coarser material, while the other two, upper and lower, are furnished with No. 10 sieves for the fine stuff. The ore that enters upon the upper sieves is therefore rewashed on the lower sieves, in order to ensure a more effective separation. The overflow of the two upper sieves of either degree of fineness, that is, the material discharged at *q*, is washed again upon one of the lower sieves of the same degree of fineness—the overflow from that sieve being worthless gangue—while that which passes through the sieve is second quality ore, or blende and copper mixed. The stuff that passes through the two upper sieves of either degree of fineness is delivered from the outlet-pipes *o*, and comes upon the remaining sieve of corresponding degree of fineness, the material which passes through that sieve being of first quality, while the overflow at *q* is of second quality.

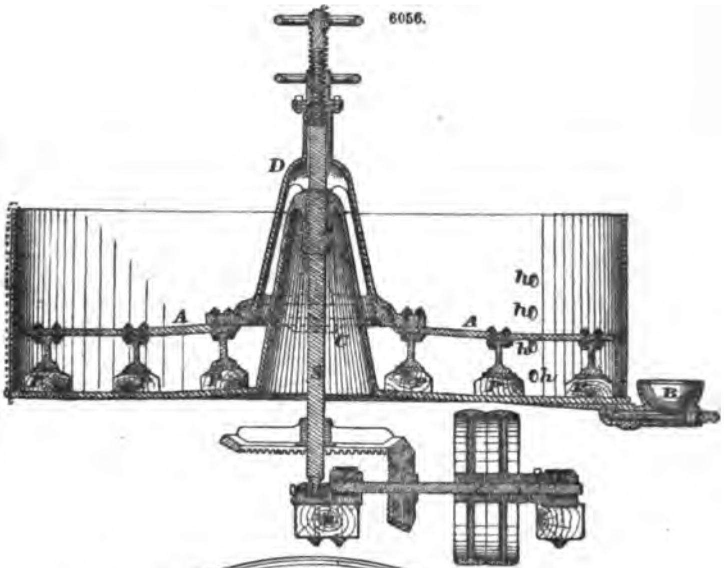
By this arrangement there are three products obtained; the pure galena, which is almost entirely free from other mineral; the zincblende and grey copper, mixed with heavy spar and quartz, almost free from galena; and the gangue, which is very clean and free from valuable mineral.

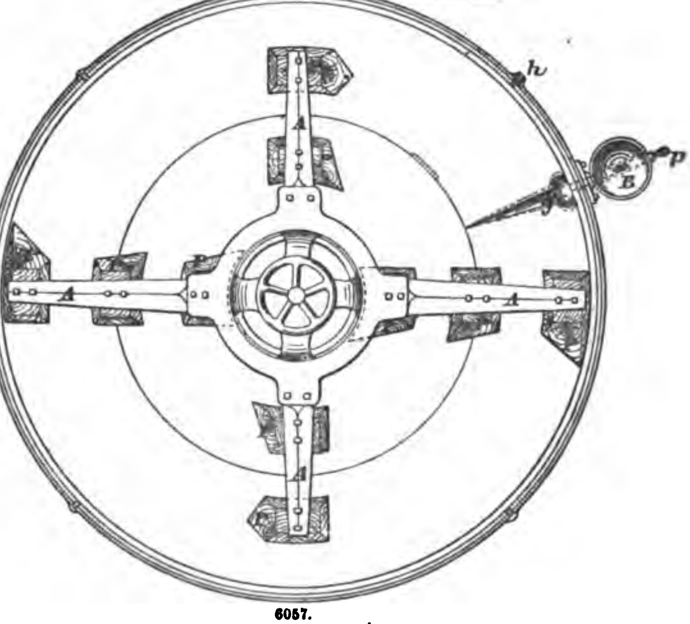
The eight sieves, or four double machines, are capable of treating 20 to 30 tons of ore a day; and as the stuff is all washed twice, the capacity of each double machine for a single washing is from 10 to 15 tons a day.

In the treatment of certain of the Comstock ores by the process of pan amalgamation, the settlers or separators used are similar to Figs. 6056, 6057. A hollow pillar or cone C is cast in the centre of the bottom, within which is an upright shaft S. This shaft is caused to revolve by gearing below the pan. To its upper end is attached a yoke or driver D that gives revolving motion to arms A, extending from the centre to the circumference of the vessel. The arms carry a number of stirrers of various devices, usually terminated in blocks of hard wood P, that rest lightly on the bottom. No grinding is required in the operation; but a gentle stirring or agitation of the pulp is required in order to facilitate the settling of the amalgam and the quicksilver. The stirring apparatus, or muller, makes about fifteen revolutions a minute. The settler is usually placed directly in front of the amalgamating pan and on a lower level. so that the pan is readily discharged into it. In some works two pans are discharged into one settler, the operation of settling occupying four hours, or the time required by the pan to grind the amalgamate another charge. In other works the settling is only allowed two hours, and the two pans, connected with any one settler, are discharged alternately. The consistency of the pulp in the settler is considerably diluted by the water used in discharging the pan, and by a further supply which is kept up during the settling operation. Occasionally, however, the pulp is brought from the pan into the settler, with the addition of as little water as possible. and allowed to settle for a time by the gentle agitation of the slowly-revolving muller, after which cold water is added in a constant stream. The quantity of water used,

affecting the consistency of the pulp, and the speed of the stirring apparatus, are important matters in the operation of settling or separating. Since the object of the process is to allow the quicksilver and amalgam to separate themselves from the pulp and settle to the bottom of the vessel, it is desirable that the consistency should be such that the lighter particles may be kept in suspension by a gentle movement, while the heavier particles fall to the bottom. If the pulp is too thick, the metal will remain suspended; if it is too thin, the sand will settle with it. Too rapid or too slow motion may produce similar results, because by too violent motion the quicksilver will not come to rest on the bottom, while, if the motion is too slow, the coarser sand will not be kept in circulation.

6056.





6057.

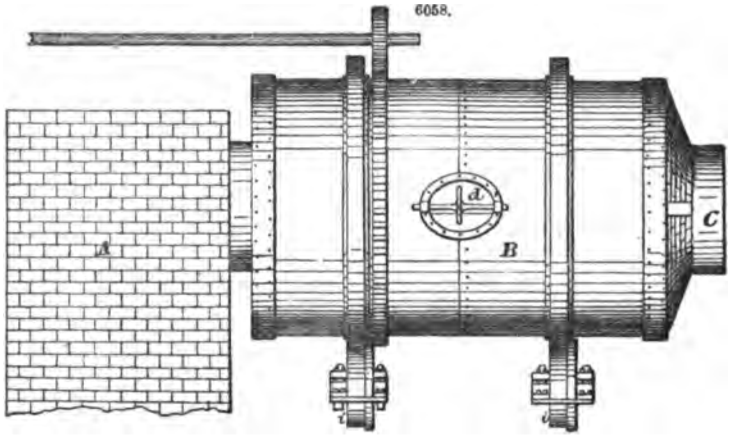
A discharge-hole near the top of the settler permits the water carrying the lighter portion of the pulp to run off, and at successive intervals the point of discharge is lowered by withdrawing the plugs from a series of similar holes *h*, *h*, in the side of the settler, one below the other, so that finally the entire mass is drawn off, leaving nothing in the settler but the quicksilver and amalgam.

There are various devices for discharging these. Usually there is a groove or canal in the bottom of the vessel, as in Figs. 6056, 6057, leading to a bowl B, from which the fluid amalgam may be dipped or allowed to run out by withdrawing the plug *p* from the outlet-pipe.

The quicksilver, charged with amalgam, is carefully cleaned by washing with water, and removing from the surface the associated impurities, such as heavy particles of dirt or pyrites. In some cases the cleaning is performed in a small iron pan resembling the settler in manner of construction, but much smaller, in which it is stirred slowly with plenty of clean water, which serves to wash out the impurities and remove them from the pan. When properly cleaned the amalgam is strained through a canvas filter or conical bag 10 or 12 in. in diameter at the top, and 2 or 3 ft. long. The quicksilver is drained off and returned to the pans for further use, while the amalgam is thus obtained for the retort.

Brückner's cylinder, Figs. 6058 to 6060, is a contrivance designed to roast ores with salt at a much

6058.



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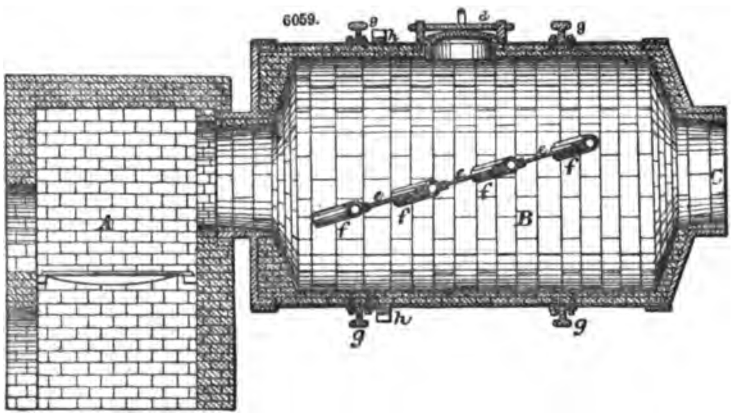

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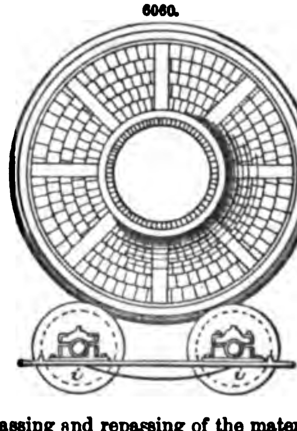


less manual labour than is involved in the operation of the reverberatory furnace. It is a horizontal cylinder, commonly about 11 or 12 ft. long and 5 or 6 ft. in diameter, constructed of iron, usually boiler-plate, and lined with fire-brick. It is supported on rollers *i*, so that it may turn freely when set in motion by the revolving gear *h*. One end of the cylinder communicates with a brick fire-place A, while the opposite end C is let into the stack, so that the frame of the fire-place passes through the interior of the cylinder. Within the cylinder there is a diaphragm or partition running longitudinally through the greater part of its length. This partition is made of iron, and covered with fireproof material. It is usually made in sections *e*, which are held in grooves that are formed in the ribs *f*. These ribs are made in tubular form, with open ends, which, extending outward beyond the side of the cylinder, permits the passage of air, and are thus partially cooled.

When the several sections are in place, the entire partition or diaphragm has the form of a rhomb whose ends are obtuse angles. It is placed at an angle of 10° or 15° with the longitudinal axis of the cylinder, so that as the cylinder, containing a charge of ore, is revolved, the diaphragm causes a continuous passing and repassing of the material from one end to the other, and ensures at the same time an intimate mixture of the whole mass.

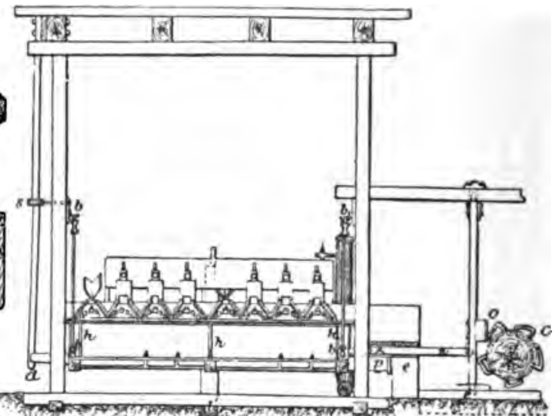
A door *a*, for charging and discharging the ore, is placed in the surface of the cylinder opposite the partition. The outside of the cylinder is provided with ribs or flanges *g* concentric with the axis of revolution, which rest on the rollers *i*; also with a toothed rib with which the pinion is placed in gear at *h*, causing the whole to revolve. The fire-place and chimney are built of brick or stone, with funnels large enough for the ends of the cylinder, which may fit into their place easily and revolve.

Between the end of the cylinder and the stack there is a dust-chamber, in which the fine material that is carried through with the draught may have an opportunity of settling.

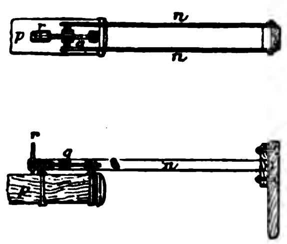
The charge of ore for this cylinder consists of 3000 to 4000 lbs., mixed with from 6 to 10 per cent. of salt. The cylinder revolves slowly, making only one or two turns a minute.

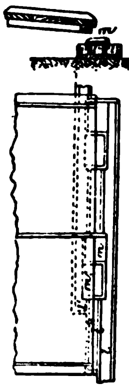
Rittinger's Percussion Table.—Fig. 6062 is front elevation of a double Rittinger table; Fig. 6064, a plan, Fig. 6066, a side view; Figs. 6061, 6063, 6065, details. This apparatus consists of a wooden

6062.

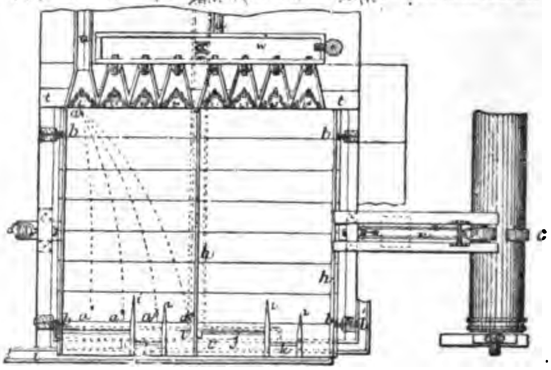


6061.





6063.



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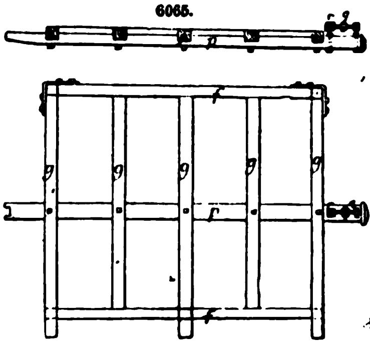
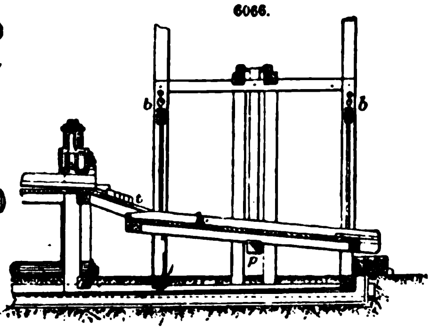
6065.



6066.



table, or platform, about 4 ft. wide and 8 ft. long, which is suspended by iron rods at the four corners, as *b*, *b*, Figs. 6062 to 6066, presenting an inclined plane, over which the water and material, supplied at the upper end, may flow evenly toward the lower end. The table is so hung as to

move freely, in a lateral direction, when acted upon by a cam *c*, and may be thrown back by the action of a spring *d*, so as to strike forcibly against a timber *e*, firmly imbedded in the ground, by which means a shock is imparted to the table and the material upon it.

The characteristic features of this table, as compared with the ordinary percussion-table, are that the shock is applied at one of the long sides instead of at the end, and that it is self-discharging and continuous in its operations. On the old-fashioned percussion-table—the material being supplied at the upper end and evenly distributed across the width of the table by a stream of water, and the shock being imparted at the same end—the tendency of the heavier particles is to move backward at each throw or shock of the table, while the lighter particles, following the impulse of the stream, move downward toward the front edge, and are there discharged. In the case of the Rittinger-table, all the particles, which are fed at the upper end and near one side, move downward with the stream; but as the percussion is applied at the opposite side, they obtain at each throw of the table a lateral motion, which varies in amount according to the density of the particles, so that the heaviest—the grains of ore—move entirely across the table to the side opposite to that at which they entered; the lighter particles, or grains of ore and gangue combined, move part way across, while the lightest, or grains of earthy character, move downward in a nearly straight line, describing curves, as at *a*, *a'*, Fig. 6064. By this means a separation of the particles is effected, according to their density, and as they are discharged at different parts of the front edge of the table, they may be received there in separate troughs provided for the several classes; the first, consisting of nearly pure ore, being ready for smelting or other metallurgical treatment; the second, consisting of mingled ore and gangue, may be returned for repeated dressing; and the third, nearly pure gangue, is allowed to run to waste.

Fig. 6065 shows the construction of the frame of a double table, consisting of two cross-pieces *f* and five longitudinal pieces *g*. This frame is covered by hard-wood plank or boards, which are smoothly dressed and carefully fitted together, forming the surface of the table over which the material for concentration is allowed to pass. As the top of the table, hitherto constructed of maple boards, soon begins to rot or wear upon the surface, and thus to lose its desired smoothness, it is better to cover it with a stout, waterproof india-rubber cloth, which must possess the requisite degree of smoothness, so that the fine particles of slime may not adhere to it, and should be light colour, so that the dark streaks of ore may be clearly distinguished. The cloth should be applied to the table when warm, so that it may be well stretched under ordinary temperature. When stretched and nailed upon the table, the edges of the cloth are covered with narrow strips of leather, in order to prevent tearing, and at the upper end it is covered with a strip of zinc, 10 or 12 in. wide, upon which the water and solid material fall from the distributing boards, passing thence quietly on to the cloth. Such a cloth-covering is said to last over a year, and to be especially well adapted to the treament of the finest material, only the number of shocks must be increased to 120 or 150 a minute.

The sides and upper end of table surface are furnished with bordering strips of wood *h*, and a similar strip divides the surface longitudinally in the middle, thus forming a double table. The lower end of the table is also furnished with short strips *i*, which may be moved on a pivot toward one side or the other, and the upper ends of which are pointed, to assist somewhat in the division of the several classes of the material at the place of discharge. These pointed strips may also be fixed in any desired position by driving wooden wedges between them and a transverse piece of wood that crosses the table near the lower end, and is supported above it by resting on the upper edges of the side and partition strips *h*, to which it is nailed.

The lower end of the table is pierced with slits or apertures *j* and *k*, Fig. 6064, through which the material may be discharged from the table before reaching the lower edge, falling thus into troughs, which conduct the different assortments to their appropriate places. The outer of these troughs, *l*, receives the clean ore from the lower edge of the table; the second, *l'*, receives the middlings through the aperture *k*; and the inner, *l''*, receives the waste stuff through the aperture *j*.

Another arrangement for the disposition of the assorted material, without the use of apertures, is shown in Fig. 6063, in which the poor stuff or gangue is discharged over the edge of the table into the launder *l''*; the other two classes fall into the box *m*, which is divided into two parts, opening in opposite directions, that part which is under the discharging point of the clean ore opening to the right and delivering the stuff into the launder *l*, the other part receiving the middlings and delivering into the launder *l'*. The table is suspended in an upright framework by iron rods, the length of which may be somewhat increased or diminished by means of the screw near the point of support. The percussion timber *p* forms a part of the frame of the table. One end of it rests against the timber *e*, being strongly pressed in that direction by the spring *d*, which is attached to the other end. Motion is communicated to the timber *p*, and thus to the table, by rods *n*, which connect it with the perpendicular rod *o*, against which the cams *c* strike. The rods *n* are attached to *p* by means of a nut *q*, Fig. 6061, which moves on a screw, and may be adjusted for the purpose of shortening or lengthening the stroke by turning the head *r*. When the cam *c* presses against the block at *o*, it moves the table in a lateral direction, compressing the spring *d*, which, as soon as the pressure of the cam is relieved, throws the table back against the timber *e*, producing the shock, the force of which is regulated by a screw *s* applied to the middle of the spring, and entering the framework above the table. The force of the stroke is increased by screwing the spring up closer to the frame, or diminished by withdrawing the screw.

In another arrangement, motion is imparted to the table in a somewhat different manner, the cam acting directly upon the frame instead of by the means shown in Fig. 6062, thus drawing the table to one side, and then releasing it for the movement in the opposite direction. To effect this, the end of the percussion timber *p* nearest the cam is furnished with two stout iron plates, one attached to each side of the timber and extending toward the cam; the two plates are connected at their other ends by a cast-iron piece which fills the space between them, and the inner surface of

which is curved, so as to correspond to the curve of the cam. The latter revolves between the two plates, in the reverse direction from that indicated in Fig. 6062, and, striking against the cast-iron piece, draws the table to one side. When the table is released by the cam, it is drawn to the opposite side by the action of a spring, which, as in the case already described, is of wood, but is placed horizontally, the two ends being fixed, and the middle attached to the end of the percussion timber. When thus drawn forward the end of the percussion timber strikes against a buffer, which is firmly secured in an iron bed-plate that is screwed down to an underlying timber; and as the sharpness of the shock—an important condition for effective work—depends upon the firm position of this timber, the latter is made long enough to extend entirely under the table to the opposite side, and is fixed by holding-down bolts to a solid foundation of masonry. The timber is connected with and braced by other timbers that are so laid in the masonry as to distribute the shock as evenly as possible to the entire mass of the latter. The opposite end of the timber may serve as the foundation for the supports of the cam-shaft, one end of which is furnished with a driving pulley, and the other end with a 400-lb. to 600-lb. fly-wheel 3 ft. in diameter.

The movement of the table is guided by two uprights, one on each side of the percussion timber. The buffer is adjustable, and by advancing or retiring it the length of the stroke may be regulated.

The distributing board t is divided into four parts, or aprons, for each single table; each of the aprons is provided with a group of distributing points. The material for concentration is supplied from a trough u, and enters the table by the apron t'. Clear water, of which a supply is kept in the box w, the surplus flowing off through w', is furnished thence through separate cocks to the aprons t^2, t^3, and t^4, and thus distributed evenly over the table. In the manipulation of this table, the following conditions are important;—The surface of the table must be made as smooth as possible. The width of the apron, from which the material for concentration is supplied to the table, should not exceed 8 or 12 in., clear water being distributed over the remainder. If a very clean product is desired, the width of the washing surface may be increased to 4 ft., making a total width of 5 ft.; or, maintaining a total width of 4 ft., the distributing surface of the slimes may be reduced to a width of 8 or 9 in. The inclination of the table must be adapted to the character of the material to be treated; it should be about 6° for sands, and 3° for fine slimes. The supply of stuff to be treated should not exceed $\frac{3}{10}$ of 1 cub. ft., containing 15 lbs. of sands a foot, or $\frac{1}{10}$ of 1 cub. ft., containing 6 lbs. of slimes a foot. According to this, a double table will treat in twenty-four hours 4·640 tons of sands, or 0·864 ton of slimes. The amount of clear water required is about the same quantity a foot of distributing breadth as that which brings the ore upon the table; so that if the breadth of the ore-distributing surface is 1 ft., and that of the water-distributing surface is 3 ft., the quantity required for one table will be, for sands, $\frac{9}{10}$ of 1 cub. ft. a minute, and for slimes $\frac{30}{100}$ of 1 cub. ft. a minute. The quantity of clear water must be increased as the inclination of the table is decreased. The outer edge of the table, that is, the side opposite that on which the ore enters, should have a little more water than the rest of the surface, in order to carry off the heavier material that reaches that side. The number of strokes in a minute is, for sands, 70 to 80; for slimes, 90 to 100. The length of each stroke depends upon the tension of the spring d, by which the table is pressed against the block e. The spring has a length of 11 ft., a breadth of 3 in., and a thickness of 2 to 2½ in. If the spring has a tension of 180 or 200 lbs., the length of stroke should be, for sands, 2½ in., and for slimes ½ to ¾ of an inch.

Under too strong tension of the spring the table makes its return movement too speedily for the desired action of the particles; the result is that they move in the reverse direction. The operation of the table demands great uniformity in treatment, especially as regards the number of blows and the quantity of water and of material. When the stream carrying the material upon the table contains less sand or slime to the cubic foot than the maximum above given, the tension of the spring should be relieved and the inclination of the table diminished. Under ordinary conditions the average performance of a double table is from 2 to 4 tons in twenty-four hours, with a consumption of water of 1000 or 1500 cub. ft. One table requires ½ horse-power.

See Amalgamating Pan. Battery. Buddle. And articles on the various metals.

OSCILLATION. Fr., *Oscillation*; Ger., *Schwingung*; Ital., *Oscillazione*; Span., *Oscilacion*.

Centre of Oscillation.—The time of a pendulum's vibration increases with its length, being always proportioned to the square root of its length. This is strictly true only of the simple pendulum, in which the pendulous body is supposed to have no determinate magnitude, and to be connected with the point of suspension by an inflexible wire without weight. If, however, the vibrating body has a determinate magnitude, then the time of vibration will vary, not with the square root of its length, but with the square root of the distance from the axis of suspension of a point in the body called its centre of oscillation.

If each part of the vibrating body were separately connected with the axis of suspension by a fine thread, and entirely disconnected from the rest of the body, it would form an independent simple pendulum, and oscillate as such, the time of each vibration being as the square root of the length of its thread. It follows that those particles of the body which are nearest to the axis of suspension would, as simple pendulums, vibrate more rapidly than those more remote. Being connected, however, as parts of the solid body, they vibrate all in the same time. But this connection does not affect their tendencies to vibrate as simple pendulums, and the motion of the body which they compose is a compromise of these tendencies of its particles. Those nearest the axis are retarded by the more remote, while the more remote are urged on by the nearer. Among these particles there is always one to be found in which the accelerating and retarding effects of the rest are mutually neutralized, and which vibrates in the same time as it would if it were unconnected with the other parts of the body, and simply connected by a fine thread to the axis of suspension. The point in the body occupied by this particle is its centre of oscillation. By this centre of oscillation the calculations respecting the vibration of a solid body are rendered as simple as those of a molecule of inconsiderable magnitude. All the properties which belong to a simple pendulum may

be transferred to a vibrating body of any magnitude and figure, by considering it as equivalent to a single particle of matter vibrating at its centre of oscillation.

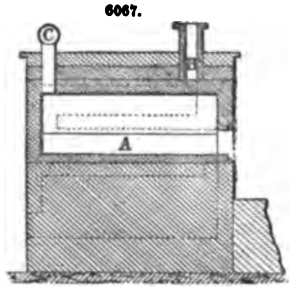
The determination of the position of the centre of oscillation of a body usually requires the aid of the calculus. It is always farther from the axis of suspension than the centre of gravity is, and always in the line joining the centre of gravity and the point of suspension, when the body is suspended from a point. The rule for finding it in such a case is; if S be the point of suspension, and O the centre of oscillation, $S\,O = \frac{\Sigma\,(m\,d^2)}{M\,S\,g}$; or it is the quotient obtained by dividing the moment of inertia of the body by the product of its mass into the distance of its centre of gravity from the point of suspension.

The centre of oscillation of a straight line or a cylinder suspended at one end, will be distant from that end by two-thirds of its length, while the centre of gravity is distant one-half of its length. The distance in an isosceles triangle of the point of suspension, the vertex, and the centre of oscillation will be three-fourths of the length of the perpendicular from the vertex upon the base. The distance of the centre of gravity from that point will be two-thirds of the length of that line.

OVENS. Fr., *Fours*; Ger., *Ofen*; Ital., *Forno*; Span., *Hornos*.

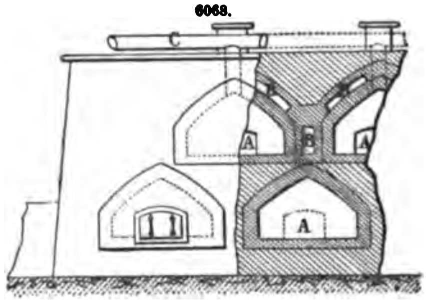
Coke Ovens.—Figs. 6067 to 6069 are longitudinal and transverse sections of the ovens invented by

6067.



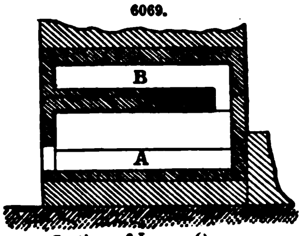
Section of Upper Ovens.

6068.



Lord Dundonald to prevent waste of small coal and the gaseous products of coal. The ovens A are built in two tiers, the one over the other; the flame from the lower ovens is carried by flues B around the outside of the upper ovens, and keeps them always at a red heat; the upper ovens are charged with small coal and closely luted, thus forming a series of retorts, in which the volatile products of the coal are distilled and pass off through the pipe C; the tar and ammonia are condensed, and the gas is used for lighting the works.

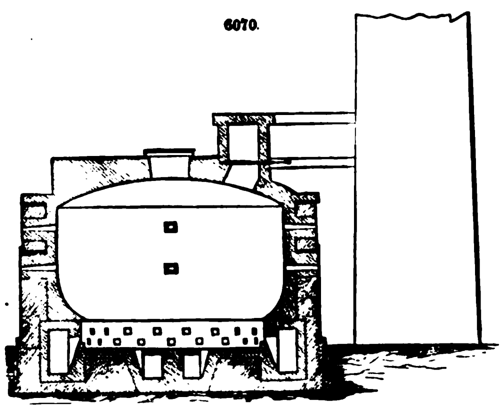
6069.



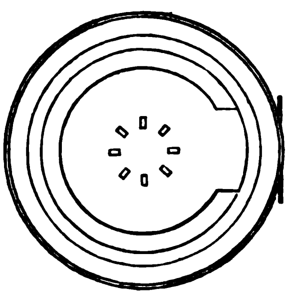
Section of Lower Ovens.

When small coal of bituminous quality is placed upon a coke hearth and the heap built upon it, it is coked by radiated heat from the heap, in this manner large quantities of small coal are still coked at some iron-works. This fact being observed would lead to the construction of ovens, where the arch over the coal being kept at a red heat answers the purpose of the coke heap. The small coal of Yorkshire and the North of England being of a bituminous character and well adapted for coking, ovens of various shapes were erected for the purpose;

6070.



6071.

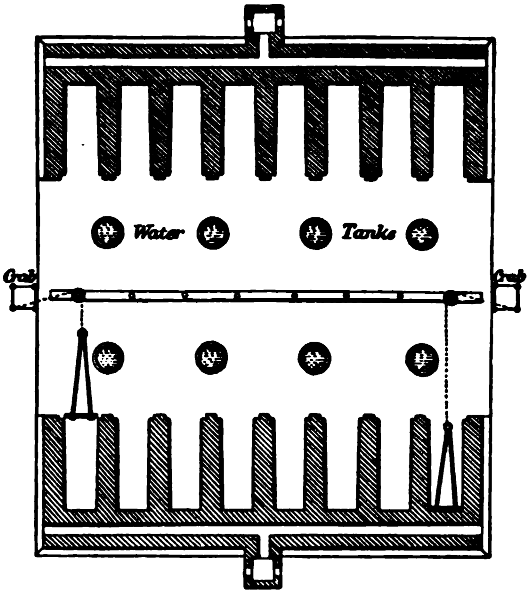


hemispherical ovens, however, are the favourite shape in the north. Fig. 6070 is a vertical section of one of the hemispherical ovens, and Fig. 6071 a sectional plan.

The great demand for superior coke, consequent on the development of the railway system, has

led to attempts at improvement in every direction; the leading object in all being to keep the oven at a high temperature, that being found an essential condition for the manufacture of dense hard coke, as afterwards explained. Figs. 6072 to 6077 show the construction of one of the most approved forms of ovens for coking, some coals containing only a small quantity of bituminous matter and requiring a high temperature; in this plan the waste gases are burnt in the flues, and thus made use of to increase the temperature of the ovens.

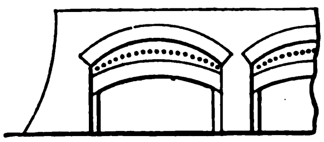
6072.



6073.

Speaking of coke for smelting purposes, I. Lothian Bell stated before the Institute of Mechanical Engineers, that in a coke oven the expulsion of the volatile constituents of the coal is effected by their own combustion, which is not the case when the coal is charged raw into the blast furnace. Hence if a form of coke oven were employed in which there was no loss of fixed carbon in the process of coking, the actual consumption of coal a ton of iron would be smaller when the coke was made in an oven than when the operation was performed in the furnace itself, because in the former case the gases themselves furnish the necessary heat, while in the latter a certain quantity of the coke itself has to be burnt for the purpose. Unfortunately, it is difficult to get rid of the gaseous constituents of the coal in coke ovens without at the same time losing a portion of the solid carbon also; nor is this to be wondered at, when the nature of the ordinary coke ovens is considered. In these the coal is exposed to a very high temperature for periods varying from seventy-two to ninety-six hours; and although air is professedly admitted in such a way as to consume the gases only, and not the coke, practically this is found to be impossible; and accordingly from a coal containing 70 per cent. of fixed carbon 62 per cent. is about all the coke that is produced.

6074.



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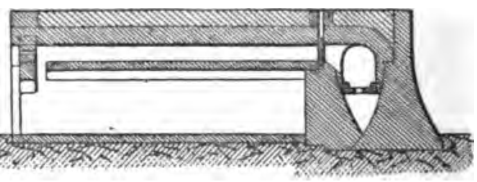
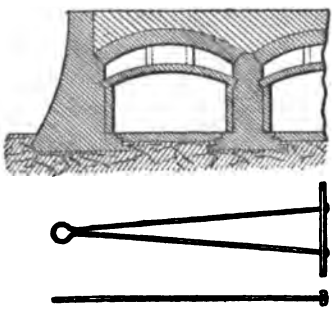
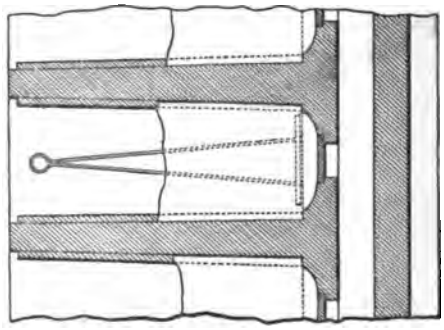




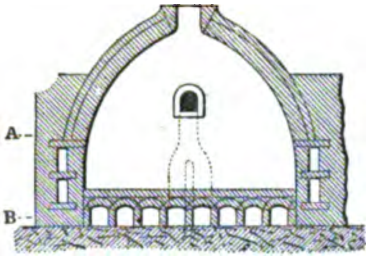
6076.



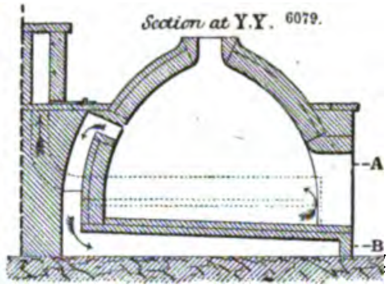
6077.

Different attempts have been made to avoid this waste of carbon in coking. In the simplest plan, which may be regarded as a palliation rather than a cure of the evil, the gases, instead of being burnt only above the coke itself in the chamber of the oven, as in the ordinary coke ovens, are conducted into flues running under the bottom and round the sides of the oven, as in that known as Breckon and Dixon's coke oven, shown in Figs. 6078 to 6081. This form of oven is more

6078. *Section at X.X*



Section at Y.Y. 6079.



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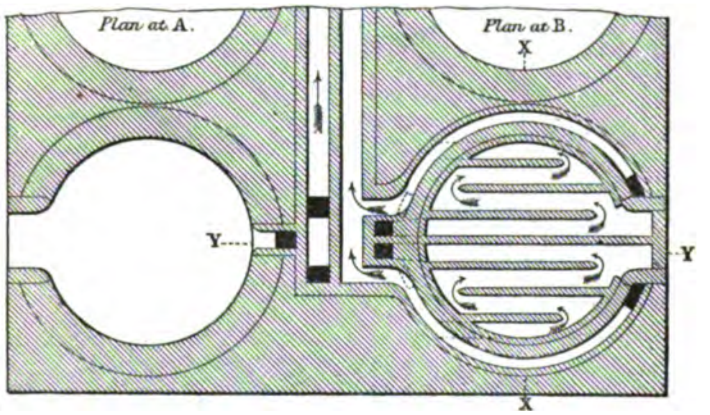
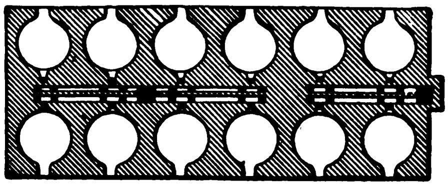
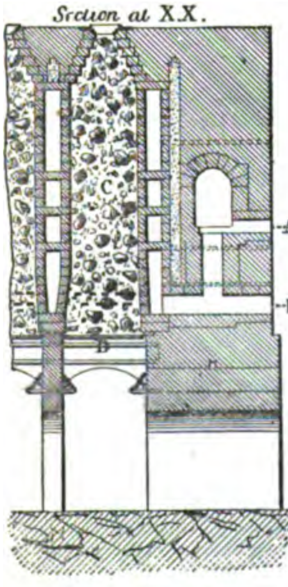


costly than the ordinary one, and more expensive to maintain in repair; but on the other hand, as the operation of coking is completed in about forty-eight hours, instead of seventy-two to ninety-six hours, as in the ordinary ovens, the shortened period of exposure affords a notable diminution in the action of the air on the coke, with a corresponding increase in the yield of coke obtained.

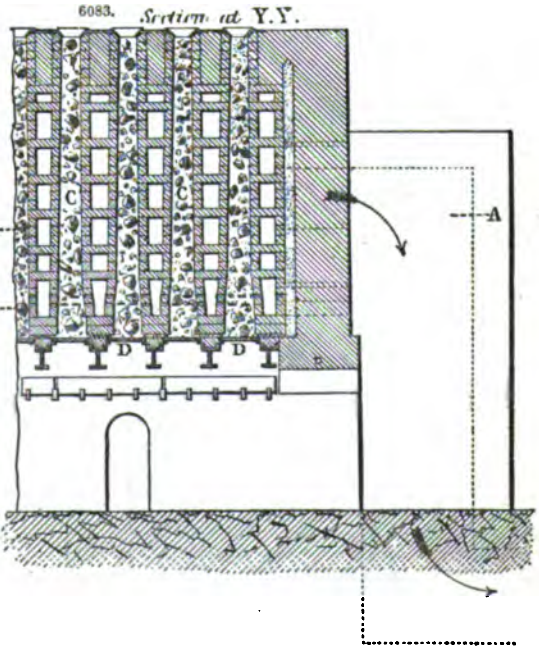
6081.



6082. *Section at X.X.*

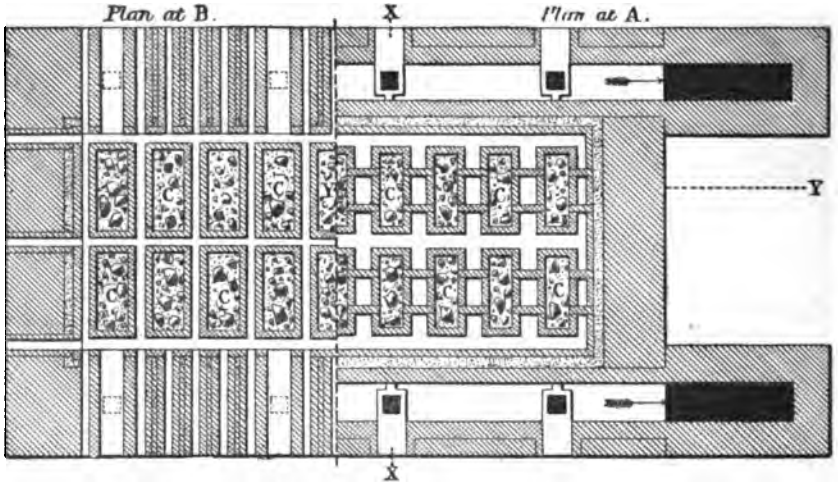


6083. *Section at Y.Y.*

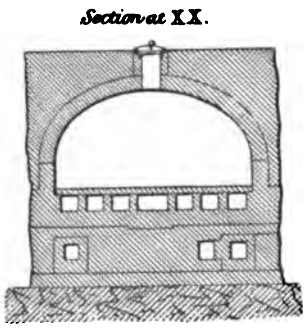


A second form of coke oven is that known as Appolt's, shown in Figs. 6082 to 6084, which consists of a series of upright rectangular chambers of brickwork C, C, generally eighteen in number,

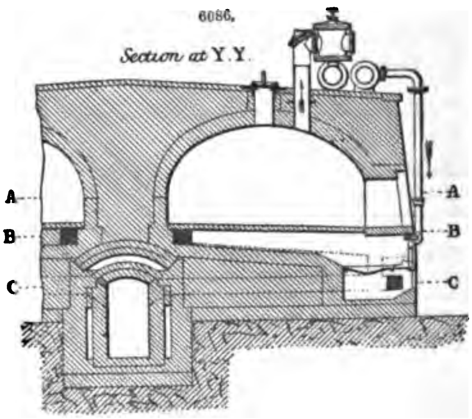
6084.



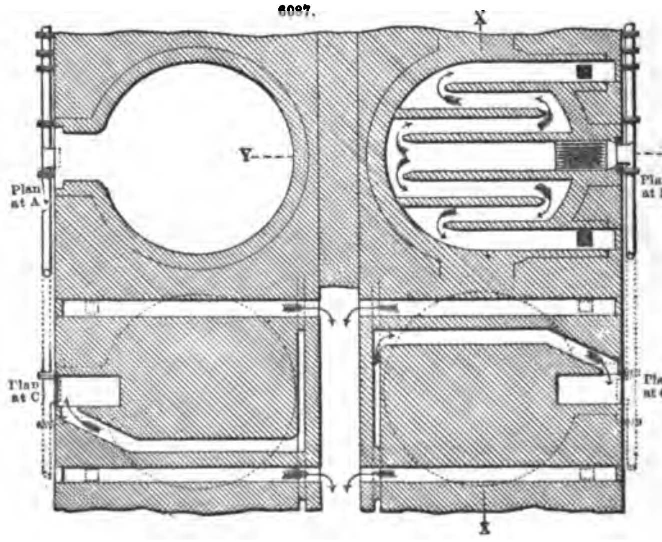
6085.



6086.

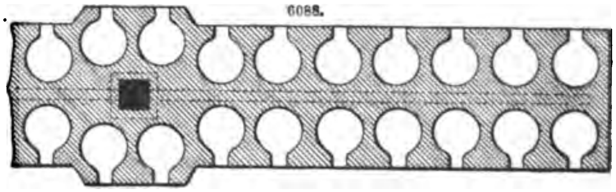


6087.



each 16 ft. high, 4 × $1\frac{1}{2}$ ft. at the lower end, and $3\frac{1}{2}$ × 1 ft. at the upper. These chambers or retorts are surrounded by flues, in which the gaseous hydrocarbons are burnt; and the resulting heat, being transmitted through the sides of the chambers, converts the coal into coke. By following a regular order of charging, sufficient heat is always maintained in the block of ovens for effecting the process of coking as soon as a fresh charge of coal is introduced. In this coke oven twenty-four hours are sufficient for the completion of the coking in any one of the chambers; and the bottom plate D being then removed, the charge falls out by its own weight, and is cooled with great expedition, and loss of coke is avoided by rapid cooling.

6088.



A third description of coke oven is the Knab or Pernolet oven, Figs. 6085 to 6088, in which, as in the preceding one, no combustion takes place in its interior, the gases being burnt in flues running under the bottom and along the sides. Instead, however, of the combustion being direct, as in the Appolt oven, the gases are conducted through a long pipe to a series of condensers, where the tar and ammoniacal liquors are collected; and the gas freed from these is then used as the source of heat for coking the coal.

In the last two forms of oven it will be observed that the coal is coked in what is virtually a close retort; and hence from these ovens a yield is obtained equal to the entire quantity of fixed carbon contained in the coal. There is little doubt, says Bell, that even after adding the extra cost of construction, wear and tear, and greater amount of labour in carrying on the operation of coking in these two ovens, the increase in the yield of coke—considered as so much combustible matter—offers sufficient inducement to have recourse to these more perfect forms of oven; and although my experience with the tar and ammonia condensation connected with the Pernolet oven was not altogether satisfactory, the results obtained in France, where the process was first established, are such as would have encouraged the continuance of the plan in this country, instead of returning, as has always hitherto been the case, to the old simple form of oven, entailing extra waste. As regards the quality of the coke produced, however, notwithstanding the difficulty of making an accurate comparison between two different kinds of fuel employed in blast furnaces, the general experience is largely in favour of coke made in the ordinary ovens without flues; and it is equivalent to something like the extra yield of coke obtained from the three forms of flued coke ovens just described. See Kiln.

OVERSHOT WATER-WHEEL. Fr., *Roue hydraulique en dessus*; Ger., *Oberschlächtiges Wasserrad*; Ital., *Ruota a cassette di sopra*; Span., *Rueda de cajones.*

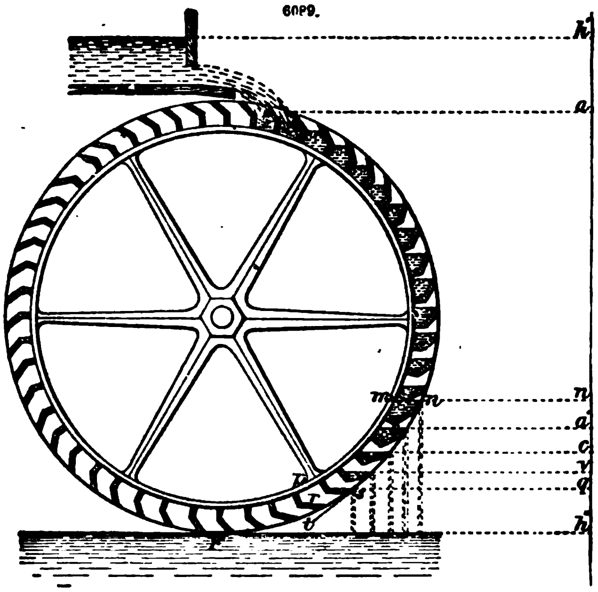
There is a want of uniformity among practical men in the application of distinctive appellations to the several kinds of water-wheels that often leads to confusion and misapprehension. Some define an overshot wheel as one that receives its water over the crown, and that consequently turns against the tail-water. According to this definition, a wheel that receives its water from a sluice situate below the crown, and hence revolves in the contrary direction, is a breast-wheel; and as this wheel may take the water at a point situate above or below the horizontal plane passing through the axis of the wheel, it is necessary to subdivide this kind into high and low breast. Others define an overshot wheel as one that receives its water at a point situate between the crown and the horizontal plane passing through the axis, and that consequently may turn either with or against the tail-water; and a breast-wheel as one that receives its water below this plane. This definition confounds the high breast and the overshot of the former definition, and necessitates the subdivisions of forward and back overshot wheels, according as the water is carried over the crown or delivered short of that point. It matters but little which of these divisions is adopted, provided it is clearly understood. The latter, it may be remarked, is the more common on the Continent, the former in this country; consequently we shall adopt the former; but to render our treatment of the subject more generally acceptable, we shall discuss the high breast under the present heading of Overshot Wheel.

The water of a stream is set in motion by the action of gravity, and consequently the motion is constantly accelerated until the resistance from friction and other sources becomes equal to the accelerating force. When this point is reached, the motion becomes uniform. To utilize the *vis viva* of the water in this state, wheels are designed, having either straight or curved floats which dip into the stream, and upon these floats or paddles the water impinges. The greatest proportion of the power of the stream that this kind of wheel is capable of utilizing is, as we have previously shown, from ·35 to ·40. If a sudden change of level occur in the bed of the stream, the water passes from one level to the other without being subjected to the retarding influence of the friction developed in the former case. Hence a greater available force is generated; and as, moreover, the whole of the mass of water can in this case be brought upon the wheel, an impossibility, as we have shown, in the case of the float-wheel, a much larger proportion of the power of the stream may be utilized. This proportion is greater in the ratio of 2 to 1; hence it follows that a fall offers the most favourable means of turning to useful account the force generated by a stream of water. But to render this force available by means of a wheel acted upon by gravity alone, the fall must not be less than 6 ft., nor should it exceed 40 ft., for above that height the construction and maintenance of a wheel become troublesome and costly. The wheel destined to utilize the power of a fall is provided with buckets instead of floats, which receive the water at the top of the fall and carry it down to the bottom, or as near these points as possible. For as only the gravity of the water is employed in this case, it is obvious that the force developed upon the wheel will increase as the vertical distance traversed by the loaded buckets. These buckets are of various forms, but

they are all designed with a view to retain the descending water as long as possible. When of wood, they usually consist of two parts; the first, which forms the bottom of the bucket, is radial to the wheel and is called the start; the second, forming the front of the bucket, is set at an obtuse angle to the start. When made of iron, they are composed of one piece, and are curved in the form of a portion of a circle, a cycloid, an epicycloid, or an Archimedian spiral, these forms being the best adapted for the retention of the water. The ends of these buckets are let into, and therefore closed by, the rims of the wheel, called the shrouding, and the back is formed by boards, also fixed to the shrouding, called sole-boards. The shrouding is fixed upon the segments carried by the arms of the wheel. When the power is taken from the shaft or axle of the wheel, these arms must be very strong, and they must be fixed upon the shaft in a manner that will not weaken the latter. Consequently in such a case the wheel is heavy, and absorbs a considerable proportion of the motive force. When, however, the power is taken from the periphery, often an inconvenient mode, the arms and axle may be of much smaller dimensions, as the strain of torsion is taken off the latter altogether. Such wheels are called suspension or spider wheels. Wood is the material most frequently employed in the construction of water-wheels, but recently wheels have been constructed wholly of iron. The latter material is the most suitable for the buckets, as it is favourable to the adoption of the curved form.

The whole fall of a water-course is the height of the surface of the water in the upper, above that of the water in the lower race, that is, the vertical distance passed through by the water in changing its level. And the power of the stream is the product of this height by the quantity of water discharged a minute. Thus, if a represent this quantity in cubic feet, and H the whole fall in feet also, the power P of the fall is Q H. To represent this as horse-power, multiply Q H by ·001892, and denoting the horse-power by N, we have $Q = \frac{528 \cdot 5\,N}{H}$. But the whole of the fall cannot be utilized. It is impossible either to take the water at the highest point, or to carry it down to the lowest; hence a portion of the fall is lost, and this portion must be subtracted from H, the whole fall, in order to obtain the effective fall h, or the available force of the fall. To determine the effective fall, let h', Fig. 6089, denote the level of the water in the upper race, and h'' that of the water in the tail-race; $h'\,h''$ then equals H, or the whole fall. Also, let a represent the point at which the water strikes the wheel, and a' the mean point of discharge. The height h'-a is requisite to give the water a velocity equal to that of the wheel, a necessary condition. And it is evident that this portion of the fall exerts no force upon the wheel, since the whole of the force generated by it is expended in producing the required velocity. The height $h'\,a$ is therefore ineffective. As the water leaves the wheel at the point a' the height $a'\,h''$ is wholly lost, and this height must be added to $h'\,a$ as non-effective. The water is on the wheel throughout the whole of the height $a\,a'$; consequently the whole of this height is effective. Hence the effective fall is $H - (h'\,a + a'\,h'') = a\,a'$. But $a\,a'$ is that portion of the wheel that is loaded with water; the effective fall is therefore equal in all cases to the height of the loaded arc, that is, the vertical distance from the horizontal plane passing through its lower extremity to its upper extremity.

6089.



The portion of the fall $h'\,a$ is employed, as we have stated above, to produce the force necessary to impart a sufficient velocity to the water; but the portion $a'\,h''$ is sheer loss, and the efforts of inventors and constructors have been directed to the reduction of this height. When the wheel is overshot, its lowest point must be clear of the water in the tail-race, because, as the wheel moves in a direction contrary to that of the tail-water, a portion of the latter would be lifted by the buckets if they dipped into it. It frequently happens that the level of the water in the tail-race is subject to considerable variation, and in such cases the wheel must be clear of the highest level. Hence the height $a'\,h''$ is always considerable in an overshot wheel. When the wheel is a high-breast it turns with the tail-water, and the buckets may dip to a considerable distance without an appreciable loss of power, provided sufficient ventilation is afforded to prevent their sucking the water. A breast-wheel therefore utilizes a larger portion of the fall than an overshot. Moreover, as the diameter of a breast-wheel may exceed the height of the fall, its *vis viva* enables it to overcome the obstruction of the back-water better than a wheel of a smaller diameter, and it may receive the water at that point where the velocity of the latter has become equal to that of the wheel, which is not always practicable with an overshot. This latter quality will therefore in

some cases reduce the height $h'\,a$, or, rather, preserve this height from being exceeded. Thus a portion of the height $a'\,h''$ is due to the nature of the wheel employed. But the greater part of this loss is occasioned by the discharge of the water from the buckets before they have reached their lowest position, and is therefore due to the form of the buckets and the action of centrifugal force. In considering the influence of the form of the buckets, it is necessary to bear in mind that there are two conditions to be fulfilled, to a certain degree incompatible with each other. These conditions are to afford a ready entrance to the water, and to retain it as long as possible. The latter condition requires that the front of the bucket shall be of such dimensions and form that the water may flow up it, as the bucket descends, to a considerable height before reaching the edge. But such an arrangement is not favourable to the ready introduction of the water; hence a certain degree of compromise must be allowed between these conflicting conditions, with its inevitable consequence, a loss of fall. The degree of compromise necessary is, however, frequently much exaggerated, especially in the case of wooden buckets. A two-part bucket is so much more easily made and repaired than a three-part, and certain angles are so much more readily found and set than others, that in most cases a great deal is sacrificed to what may be called convenience of construction. In the case of iron wheels, these conditions have less influence, because the material lending itself readily to the curved form, that which is most suitable for the buckets is easily obtained. If more care and skill, however, were shown in laying on the water, the ordinary two-part wooden bucket might be, with little additional trouble, constructed to carry its load down to that point where its action ceases to be of much value.

The loss $a'\,h''$ is, as stated above, due to the form of the buckets and to the action of centrifugal force. As it is important to know what proportion is due to each of these influences, we shall determine them separately. Leaving therefore centrifugal force out of consideration, the surface of the water in the buckets is horizontal. As the buckets descend in consequence of the revolution of the wheel, this surface approaches the edge of the front of the bucket, until it occupies the position $m\,n$. From this position to that marked P q, the water flows over the edge of the bucket. The arc F n, which measures the distance from the bottom of the wheel to the point at which the water begins to flow over, may be called the arc of first discharge, and F q the distance from the bottom to the point at which the discharge ceases, the arc of complete discharge. The latter is equal to the angle $r\,s\,t$, which the front of the bucket makes with the tangent to the circumference, which angle is, of course, known from the inclination adopted by the designer. The former is equal to the angle $r\,s\,t + m\,o\,n$, the angle which the front of the bucket makes with the surface of the water at the beginning of the discharge. Whatever the proportions of these arcs may be, we may always admit a mean arc of discharge; in other words, between q and n there is a point at which the whole of the water may be discharged at once, with the same effect to the wheel as is produced by the gradual discharge between n and q. No sensible error will be committed by taking this point as the arithmetical mean; that is, the mean arc of discharge will be F c, c being situate at an equal distance from n and q. The loss due to the form of the bucket is therefore $h''\,c$. But $h''\,c =$ the versed sine of the mean arc F c, the radius of which is the semi-diameter of the wheel. Therefore, representing the diameter by D, the angle $r\,s\,t$ by y, and the angle $m\,o\,n$ by z, we have $h''\,c = \frac{D}{l}\left\{-\cos.\left(y + \frac{z}{2}\right)\right\}$. The angle z evidently depends on the volume of water received by the buckets, as well as on their form and dimensions.

We have now to determine the loss of fall due to the action of centrifugal force. The water in the buckets of a wheel is acted upon by two forces—gravity, which acts in a vertical direction, and centrifugal force, which acts in a direction normal to that of gravity. The force impressed upon the water will therefore be the resultant of these two forces, and the direction of this resultant will be inclined to the vertical; and as the surface of a fluid is always normal to the force acting upon it, the surface of the water in the buckets will not be horizontal. Hence it follows that this surface will reach the edge of the bucket at a point in the fall above that at which it would rise to that level in consequence of the form of the buckets alone, and consequently the discharge will begin earlier; also, the surface of the water will sooner become parallel with the front of the bucket, and therefore the discharge will be completed at a higher point. The mean point of discharge will thus be situate at a greater height from the bottom than in the preceding case, namely, at a' instead of c, and the portion of the height $h''\,a'$, due to the action of centrifugal force, is $c\,a'$. The surface of the water in the buckets is slightly cylindrical, in virtue of the two forces acting upon it, and it is necessary to know the centre of curvature in order to be able to determine the position of the point a'. In a former article, on Angular Velocity, Fig. 210, it was shown how this centre may be determined graphically when the relative values of the two forces are known, and it was also shown that this radius $= \frac{g}{\omega^2}$, ω being the angular velocity of the wheel. This value of r furnishes us with a ready means of determining the centre of curvature. Representing the number of revolutions a minute by n, we have $\omega = n\frac{\pi}{30}$; therefore $\omega^2 = n^2\frac{\pi^2}{900} = n^2 \cdot 010965$. Consequently

$$r = \frac{g}{n^2 \cdot 010965} = \frac{32 \cdot 22 \div \cdot 010965}{n^2} = \frac{2938}{n^2}.$$

Hence, to find the vertical height of the centre of curvature above the centre of the wheel, we get the following practical rule;—

Divide 2938 by the square of the number of revolutions a minute; the quotient will be the height sought, in feet.

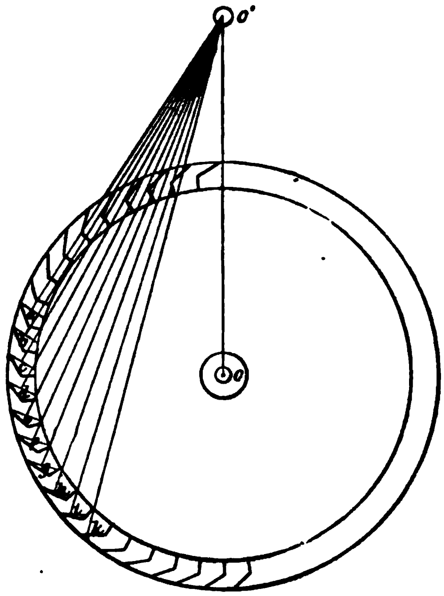
Example 1.—To find the centre of curvature of the surface of the water in the buckets of a wheel making six revolutions a minute. The square of 6 is 36, and $\frac{2938}{36} = 81 \cdot 6$ ft. The centre is therefore situate in the vertical plane passing through the axis of the wheel, and at a distance of 81 6 ft.

above this axis. This example shows that, in the case of ordinary velocities, the surface of the water in the buckets may be considered as plane and normal to the line drawn from the centre of curvature to the middle of that surface.

Example 2.—To find the centre of curvature when the wheel makes twelve revolutions a minute. The square of 12 is 144, and $\frac{2938}{144} = 20 \cdot 4$ ft. Thus, in this case, the centre may be near the circumference of the wheel, and consequently the surface of the water cannot, without sensible error, be considered plane.

Having determined the centre of curvature, draw from this centre O′, Fig. 6090, to each bucket, at the point situate midway between the inner and the outer circumference, the straight lines O′*a*, O′*b*, O′*c*, and so on. Draw normals to these lines, passing through the end or lip of the buckets. The capacity of the buckets below these lines will then represent the quantity of water they will carry without spilling. When this quantity is equal to that received by the bucket, the point of first discharge will have been reached, because immediately after passing this point the water will flow over. From this point *f* the discharge continues until the normal coincides with the front of the bucket, as at *k*, when the whole of the water will pass out. The portion of the circumference *f k* is therefore the arc of discharge, and $\frac{f\,k}{2}$ that is, the middle of the arc *f k*, is the mean point of discharge, or limit of the effective fall. The point *k* is determined by the coincidence of the normal to the radius of curvature with the fore part of the bucket. To determine *f*, it is necessary to calculate the cubical contents of the bucket, and to compare it with the capacity of the latter below the normal. When the centre of curvature is near the circumference of the wheel, that is, when the velocity of the wheel is great, instead of straight lines, arcs must be described from this centre, passing through the edge of the buckets, as in the former case, and the capacity calculated for this curved surface.

6090.



It is manifest from the foregoing considerations that the lower limit of the loaded arc depends, first, upon the form of the buckets, and, second, upon the velocity of the wheel. Hence, as this velocity is diminished, the arc, and consequently the effective fall, is increased. We have shown, however, that in the case of a wheel making six revolutions a minute, the centre of curvature is situate at a great vertical distance above the axis of the wheel; the arc will therefore increase very slowly as we diminish the velocity below this rate; in other words, the loss of effective fall due to the action of centrifugal force is very little in a wheel making less than six revolutions a minute.

It has been shown, too, that a volume of water acting by its gravity exerts twice the force of the same volume of water when acting by its impulse. Hence it will be advantageous to increase the height of the loaded arc at the expense of that portion of the fall situate above the first-loaded bucket, that is, to take the water as near the top of the fall as possible. But it is evident that if the circumference of the wheel possesses a velocity greater than that of the water, the latter can exert no force upon the wheel until it has descended through a sufficient space to acquire a velocity at least equal to that of the wheel. Moreover, the buckets will strike against the water, some of which will be dashed over and lost, and the wheel will be retarded thereby. There will be no advantage, therefore, in diminishing the height *h′ a* below what is requisite to give the water a velocity equal to that of the wheel. Hence it follows again that the height of the loaded arc will increase as the velocity is diminished; therefore, from the above considerations, it is manifest that the lower the velocity of the wheel, the greater will be the proportion of the force utilized by the wheel to the whole force of the fall. From this fact Smeaton deduced a rule which he laid down as inviolable, and which, until very recently, has been strictly adhered to by makers, namely, that the velocity of the circumference of a water-wheel should be reduced to the lowest practical limit. It is not possible in practice to deliver the water upon the wheel at the top of the fall; *h′ a* must therefore of necessity have some value, and this value will be at least sufficient to bring the water upon the wheel with a velocity of 3·5 ft. a second. This velocity is consequently the lowest practical limit, and is the one adopted by Smeaton. This rule has been generally followed by millwrights, who have designed the motor wheel to revolve with a velocity of 3½ ft. at the circumference, and then introduced gear work between the wheel and the machine to bring the speed of the latter up to the required rate. We cannot but regard this practice, however, as altogether wrong if followed out strictly. We have seen that a wheel making six revolutions a minute loses only a small portion of the fall from the action of centrifugal force when the diameter of the wheel is not great. Suppose a wheel 22 ft. in diameter. If it has a velocity at the circumference of 3½ ft. a second, it will make about three revolutions a minute, and with double this velocity, it will make six revolutions a minute. The loss of fall from the action of centrifugal force due to the greater angular

velocity will be represented by $\frac{g}{\omega^2} - \frac{g}{4\omega^2}$, the value of which will not be great. To bring the water upon the wheel with the increased velocity, an additional head of 9 in. will be required. This will be the loss of fall above the wheel, due to the greater velocity. Representing the value of $\frac{g}{\omega^2} - \frac{g}{4\omega^2}$ in feet of fall by m, and the additional head, also in feet, by n, we have the total loss of fall due to the greater velocity $= m + n$, the value of which in the above case may be taken approximately as 1¾ ft.

Now, what is the gain to set off against this loss? In the first place, the *vis viva* of the faster wheel will ensure in every case greater steadiness and regularity of motion, and this is an important advantage. But if the greater velocity will remove the necessity for intermediate gear-work, the balance will certainly be on the side of the greater velocity; for the proportion of the motive force absorbed by gearing of all kinds is enormous—a fact too often lost sight of by those who design machines. To determine the velocity of a water-wheel, therefore, it will be necessary to take into consideration the particular conditions under which it has to work, the nature of the machinery it is required to drive, and the kind of work the machinery has to perform; so that the velocity will depend almost entirely upon circumstances unconnected with the wheel itself. There are, however, limits beyond which it is well not to go.

Our investigation of the influence of centrifugal force showed that above six revolutions a minute the value of m increases rapidly, and as n increases as the square of the velocity, that is, in a like proportion, the value of $m + n$ would become sufficiently great to occasion a serious loss of fall, or $\frac{m+n}{H}$ approaches too nearly in value $\frac{H}{H}$. The extreme limit to the velocity of the circumference may be fixed at 10 or 11 ft. a second. It is equally clear that we cannot descend below Smeaton's velocity of 3½ ft. a second without loss, since our investigations have also shown that a wheel moving with this velocity exerts the greatest possible effect, or rather utilizes the largest possible proportion of the total force H Q of the fall; for, as we have seen, it by no means follows that a wheel in those conditions transmits the greatest possible effect to the machine, a large proportion being frequently absorbed by the intermediate gear-work. We may therefore lay down, as a rule, that the velocity of the circumference of a water-wheel may not be less than 3·25 ft. a second, nor greater than the square of 3·25 ft., and that within these limits the velocity must be determined according to the nature of the work to be performed.

We have seen that the water must arrive upon the wheel with a velocity equal to that of the circumference; therefore, when the velocity of the latter has been determined, we have next to consider what portion of the fall is required to produce this velocity. Theoretically, the velocity due to the head of water is expressed by $V = \sqrt{2gH}$; but the contraction at the orifice and friction will modify V considerably. Moreover, in the case of a forward overshot, the water flows upon the wheel from a wheel-race, and falls freely through the distance from this race to the wheel. Consequently the falling water describes a parabola; and as the extent of this curve depends upon the velocity, it cannot be determined until the velocity is known. But the free entrance of the water into the buckets will depend, in a great measure, upon the proper directing of this curve; and hence it becomes necessary to determine the exact point at which the water meets the wheel, as well as its exact velocity at that point. Careful attention to these matters is requisite whenever it is important to utilize as much as possible of the power of the fall; in other words, whenever it is important to economize water. The researches of Poncelet, Lesbros, and Morin, who followed in the wake of Borda and Michelotti, have furnished us with the means of solving the foregoing problems readily and accurately.

To find the Velocity of the Water upon the Wheel-race.—Though the presence of a wheel-race beyond the sluice does not influence the discharge, it diminishes the velocity of the water after it has passed the orifice. The fluid vein spreads out and the mean velocity becomes less. The following formula gives the velocity of the water after it has passed the sluice by a distance equal to twice the depth of the opening; $U = \frac{\sqrt{2gH}}{\sqrt{1 + \left(\frac{1}{m} - 1\right)^2}}$

In this formula u is the velocity sought, and m the coefficient of discharge for the given orifice.

The following rule will, however, be found sufficiently accurate for practical purposes.

To find the velocity at a distance from the opening equal to twice its depth, multiply the velocity due to the head by 0·85.

To find the Velocity of the Water at the edge of the Wheel-race.—A wheel-race is usually so short that the influence of friction may be neglected. If, then, we represent the velocity at the edge by u, the head due to the mean velocity at the point situate at twice the depth of the opening by H^1, and the inclination of the race, that is, the height of the lower side of the opening above the extremity of the race by h, we shall have $u = \sqrt{2g(H^1 + h)}$.

To draw the Curve described by the mean Particle of the Fluid Vein, after leaving the Wheel-race.—When the velocity of the water at the end of the wheel-race is known, it is easy to trace the curve described by the mean particle of the fluid vein after it has left the race. Let u = that velocity; a = the angle of that velocity and of the wheel-race with the horizontal; x = the abscissa of the curve measured upon a horizontal line drawn through the middle of the section where the mean velocity is u, and y = its vertical ordinates from the same origin. The following formula then gives the value of y; $y = \frac{g x^2}{2 u^2 \cos.^2 a} + x \tan. a$.

By giving x values equal to 1, 2, 3, 4, &c., inches, we shall obtain the corresponding values of y, and the curve may be traced through the points thus found.

When the wheel-race is horizontal, we have $a = o$, cos. $a = 1$, tan. $a = o$, and $y = \frac{g x^2}{2 u^2}$.

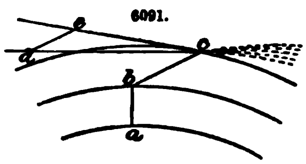
In the case of an overfall, we may find the velocity of the mean particle approximatively from the formula $u = \sqrt{2 g \times 0 \cdot 6 \mathrm{H}}$; because the depth of the water upon the crest or sill of an overfall is only about 0·80 of the height H of the level above this same point, and therefore, the mean particle being at 0·60 of this height, its velocity will be that given by the above formula, and will be nearly in the horizontal direction. It will thus be easy, in every case, to determine the parabola described by this mean particle.

To find the Velocity of the Water on its arrival upon the Wheel.—At the point where the curve described by the mean particle meets the outer circumference of the wheel, draw a tangent to the curve; the direction of this tangent will be that of the velocity V of the water on its arrival upon the wheel. Then to the height due to the velocity u, add the height from this point of meeting to the origin of the curve. The velocity due to the sum of these heights will be the velocity V with which the water arrives upon the wheel.

We have already shown that the water should reach the circumference of the wheel with a velocity at least equal to that of the circumference. But to ensure the buckets filling properly, and, at the same time, to prevent the water from striking against the outer face of the buckets, it should possess a velocity slightly in excess of that of the circumference. This velocity may be determined in the following way;—

Having found the point c, Fig. 6091, at which the mean particle meets the circumference of the wheel when the velocity of the water at that point is equal to that of the circumference, and the direction of the velocity V at that point; from the same point, draw a tangent to the outer circumference of the wheel. Set off upon this tangent, to any scale, a length $c\,e$ to represent the velocity of the circumference. Through the point c draw the profile $a\,b\,c$ of a bucket, and from the point e, parallel to the face $b\,c$ of the bucket, draw a line to meet the direction of the velocity of the water at c. The length $c\,d$ will then represent, to the same scale, the velocity which the water should possess at the point c.

6091.



When the velocity of the wheel has been determined, the portion of the fall $h'\,a$, Fig. 6089, requisite to give the water the due velocity is thus readily found. Representing this quantity by h, we have $\mathrm{H} - h =$ the height of the bucket into which the water is delivered, and this height will determine the diameter of the wheel. In the case of an overshot, it is obvious that the diameter can exceed the height $\mathrm{H}-h$ by only a very small quantity, since the water has to be brought over the crown of the wheel. Instances are frequently met with in which the diameter has been made equal to this height, that is, in these cases the water is delivered upon the crown of the wheel. A greater effect, however, may be obtained by carrying the water over the crown and delivering it at about 25° below, that is, at 65° above the horizontal plane passing through the axis of the wheel, as this arrangement gives a larger diameter. The radius of the wheel, in this case, is given by the formula $\mathrm{R} = \frac{\mathrm{H}-h}{1 + \sin. 65^\circ} = \frac{\mathrm{H}-h}{1 \cdot 9}$.

If the wheel is a high-breast, its diameter is likewise determined by the height $\mathrm{H} - h$, but evidently it may considerably exceed that height or even H, because in this case the water is not carried over the top of the wheel. Practically, however, this wheel cannot be made much larger than the overshot. One of the advantages of this wheel is that the water may be applied to it at the point which gives the greatest effect; and this point is situate at 52° 33′ from the summit of the wheel, or 37° 27′ from the horizontal plane passing through the axis, because at that point we get the greatest possible height of loaded arc, with the greatest possible radius. The diameter must therefore be determined so that the wheel may take the water at this point, and to fulfil this condition the radius is found by the formula $\mathrm{R} = \frac{\mathrm{H}-h}{1 + \sin. 37^\circ 33'} = \frac{\mathrm{H}-h}{1 \cdot 61}$.

As this kind of wheel moves in the same direction as the tail-water, it may, without appreciable loss, dip a few inches into it, and in such a case H must be increased by that quantity.

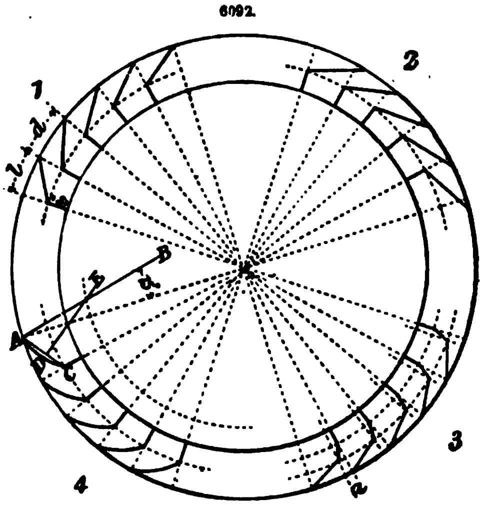
The form to be given to the buckets of a wheel is a consideration of the highest importance. As we have already seen, the loss of fall $a'\,h''$, Fig. 6089, may be attributed wholly to the form of the buckets. For though we have shown that a portion of that loss is due to the action of centrifugal force, it would be possible, were no other conditions imposed, to counteract the effects of this force by the form of the buckets. Thus nothing could be easier than to construct a bucket that should take the whole of its water down to the lowest point. But there are two other conditions to be fulfilled, and these are, first, that the bucket shall receive the water while under the sheet that is poured on to the wheel; and, second, that the bucket shall not carry its water beyond the vertical line passing through the axis of the wheel. For it is evident that if the bucket does not receive the whole of its water while in that position, a portion of the water will fly off and be lost, whilst the remainder will fall into the buckets at a lower point; and it is equally evident that if the water be carried beyond the vertical it will destroy a portion of the work of the water in the descending buckets. To these conditions may be added a third, namely, that the form adopted shall be easy of construction. Engineers and millwrights have sought to ascertain what form best fulfils these antagonistic conditions, or rather, what form constitutes the most advantageous compromise between them; and though the problem has not yet been solved with sufficient precision to lead to uniformity of practice, wheels are now constructed that leave little to be desired in this respect. The adoption of iron as the material of

construction has simplified the question in a great degree, for with the introduction of this material, the third condition mentioned above, which in practice is one of great importance, may be considered to be eliminated, since, within certain limits, one form can be as readily produced as another. But when wood is used, a good deal must be sacrificed to this condition. The form which best fulfils the requirements of a ready reception, and a long retention of the water is obviously a curve; but this form is impracticable in wood. The form of the curve must therefore be approximated to by means of angles. The multiplication of these, however, would be attended with considerable difficulty of construction, and for this reason the number of angles in a wooden bucket never exceeds two. Buckets forming two angles are called three-part buckets, because they consist of three pieces. But even these are usually considered too difficult to construct and repair, and the common wooden bucket will be found to consist of only two parts, and consequently to contain only one angle. This angle is of about 114°, such being found to fulfil the required conditions most effectually. When iron is used, any curve may be readily obtained, and several kinds, as the segment of the circle, the cycloid, the epicycloid, or the Archimedian spiral have been employed. Each of these curves possesses certain advantages over the others, but when all the requirements of a bucket-curve are taken into consideration, the balance of advantage will, we think, be found in favour of the arc of the circle; and it is this curve that is now generally adopted. We shall therefore, in describing the methods of obtaining the curves, consider this one only.

The depth of the shrouding in overshot and high-breast wheels is usually made equal to 12 in., and the same distance is allowed between the buckets. With respect, however, to the number of buckets in a wheel of a given diameter, there is a want of uniformity in the practice of engineers. The following approximate rule is sometimes used;—In wheels from 12 ft. to 25 ft. in diameter, the number of buckets = the diameter × 2·1; in wheels from 25 ft. to 40 ft. in diameter, the number = the diameter × 2·3; and in wheels from 40 ft. upwards, the number = the diameter × 2·4. Probably the best practice is to take that number which, being exactly divisible by the number of arms, give the distance apart nearest to 12 in. For example, a wheel 20 ft. in diameter has a circumference of 62·8 ft., and supposing the number of arms to be 6, we have 60 as the number nearest to 62·8, which is divisible by 6. Taking 60, therefore, as the number of buckets, the distance apart will be $\frac{62 \cdot 8}{60} = 1 \cdot 04$ ft.

The form of the buckets is, as we have seen, a matter of great importance, and we have also seen that the form is, in a great measure, determined by the materials employed and the degree of skill available for their construction. We shall now describe the methods by which the various forms and dimensions are obtained.

6092.



Draw, Fig. 6092, with the diameter previously determined, the outer circumference of the wheel, and, with a diameter 12 in. less, describe from the same centre the inner circumference; this latter circumference will then represent the sole, and the former will limit the depth of the buckets, the distance of 12 in. comprised between the two being the depth of the shrouding. Divide the outer circumference into as many equal parts as there are to be buckets, and through the points of division draw lines to the centre. If the buckets are to be two-part wooden buckets, as in No. 1, describe from the same centre, that is the centre of the wheel, a mean circumference, and the portion of the radii cut off by this mean circle will be the starts or bottoms of the buckets. To obtain the wrist, or fore parts of the buckets, join the ends of the starts to the points of division on the outer circle corresponding to the next radius in each case. This method of obtaining the wrist is the one generally adopted for small wheels. In large wheels these portions of the buckets should be longer; and to give them the requisite additional length, set off upon the outer circle a distance beyond the next radius equal to one-fourth of the depth of the shrouding, and join this point to the end of the start, instead of the point corresponding to the radius, as shown in No. 2, Fig. 6092. It will be noticed that this method of obtaining the wrist, besides increasing its length, alters its angle, and so renders it capable of retaining the water to a lower point; but it narrows the distance between the angle of a bucket and the face of the next lower bucket. This distance may, however, be diminished to the extent shown in No. 2 without disadvantage; and the form of bucket thus obtained is decidedly superior to that given in No. 1. We think it might be applied advantageously to small as well as to large wheels.

The obtain the three-part bucket, as shown in No. 3, describe two intermediate circles, dividing the depth of rim into three equal parts. The intersection of the first of these circles with the radii will give the length of the start. Set off upon the outer circle a distance from the extremities of the radii equal to one-fourth of the depth of the shrouding, and from these points of division draw lines towards the centre of the wheel. The intersection of these lines with the second intermediate

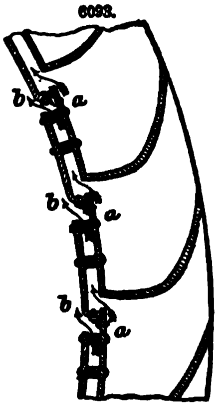
circle will give the length of the arm, to obtain which, join the point of intersection with the end of the start. The wrist is obtained by joining the end of the arm to the point of division on the outer circle corresponding to the next radius for small wheels, and to the point of division corresponding to the end of the arm for large wheels.

The mode of obtaining the curved bucket is shown in No. 4. To obtain this form, describe an intermediate circle at a distance from the inner circle equal to one-third of the distance between that and the outer circle. The intersection of this intermediate circle with the radii will give the length of the start. Join the end of the start with the division on the periphery corresponding to the next radius, as A C, for small wheels, and with a point at a distance beyond this division equal to one-fourth of the depth of the shrouding, for large wheels, as in the former cases. Bisect A C in D, and upon D erect the perpendicular D E. From the extremity A, draw A B at an angle of 15° with the radius. The point of intersection of the line A B with the line D E will be the centre from which to strike the bucket-curve with a radius = E A. The angle of 15° is the one generally adopted for overshot and high-breast wheels; but in large wheels an angle of 12° may be adopted with advantage. Wheels having buckets obtained from this angle carry their water down to a very low point in their revolution. It may be remarked that in practice the start is not straight, as shown in the figure, but rounded.

When the wheel is working at its ordinary speed, the buckets should not be more than half full, otherwise a loss of fall will be occasioned by the too early discharge of the water; in other words, the point of first discharge will depend, other things being equal, upon the quantity of water in the buckets. Consequently the breadth of a wheel will be determined by the quantity of water requisite or available. That is, the breadth of a wheel must be such that when moving with the requisite velocity, the buckets may be half filled, and no more than half filled, as they pass beneath the sluice.

Facilities must be afforded for the escape of the air contained in the buckets, otherwise the water will not enter freely. Various expedients have been resorted to, such as boring holes in the sole-plate, for example. This mode of ventilating, however, is objectionable, on the ground of allowing a portion of the water to escape. The best system of ventilation consists in a proper delivery of the water. If the sheet of water which is poured upon the wheel be thinner than the breadth of the opening between the buckets and shorter than the length of the buckets, the air will escape freely as the water enters. There is, however, one case in which some other system of ventilating becomes necessary, and that is when the wheel has to work in back-water. In some districts this is a very frequent case, and consequently a suitable provision must be made for it. The system generally adopted in such cases is that introduced by Wm. Fairbairn, and is shown in Fig. 6093. As the water enters, the air in the bucket passes out through the opening in the sole-plate, as shown by the arrows *a*, *b*, and as the bucket rises from the back-water, the air re-enters and prevents the water from rising with it, or, as the millwrights term it, prevents the bucket from sucking. When ventilated in this way, a wheel will work satisfactorily in several feet of back-water.

6093.



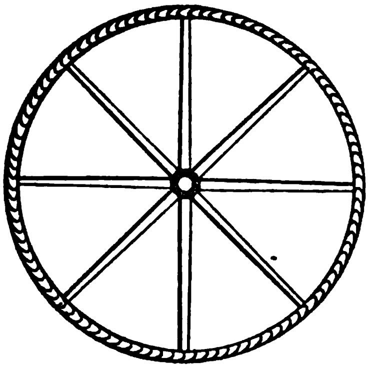
The dimensions of the arms and axle are calculated in the usual manner according to the strain brought upon them, and the nature of the materials employed. The following formula is applicable to the gudgeons; W being the weight upon the gudgeons in cwts., and D the diameter of gudgeon-journal in inches, $D = \sqrt[3]{\cdot 86\,W}$ for wrought iron, and $D = \sqrt[3]{W}$ for cast iron.

When the height of the effective fall is known, the work of the wheel may be readily calculated. Thus we have seen that the total power of a fall is Q H, and that the effective power, that is, the force which may be utilized, is Q h. The effective fall h is equal to the mean height of the loaded arc, which is the vertical distance from the point at which the wheel receives the water to a point situate half-way between the points of first and final discharge. To determine the work of a wheel, therefore, find the effective fall h and the quantity of water Q expended a minute; then the force impressed upon the wheel is Q h, which is the total or absolute work of the wheel. The useful work, that is, the force it is capable of transmitting to the machinery, is $Q\,(h - x)$, x being the quantity of work absorbed by the friction of the gudgeon-journals, expressed as feet of fall. The effective horse-power of the wheel is $P = \cdot 001892\;Q\,(h - x)$, and the quantity of water necessary to exert a given force is $Q = \dfrac{5288 \cdot 5\,P}{(h - x)}$. In a well-designed and carefully-constructed wheel, Q h should equal ·80 Q H; it is rarely, however, that this high percentage of work is obtained, ·70 Q H being the limit seldom exceeded, engineers having apparently become satisfied with the type of wheel that gives this result.

The preceding method of calculating the work of a wheel is probably the readiest, as well as the most accurate. The following formula, due to M. Poncelet, has been found to give very exact results, $P\,v = 48\,Q\,h + 6\,Q\,(V \cos. a - v)\,v$, in which P represents the weight raised by the circumference of the wheel, and v the velocity of that circumference in feet a second, and therefore $P\,v$ = the work of the wheel. The remaining symbols Q, h, V, and a, represent respectively the quantity of water in cubic feet a minute, the vertical distance from the bottom of the wheel to the point in which the mean particle of the fluid vein meets the circumference of the wheel, the velocity of this mean particle, and the angle formed by a tangent to the curve of this velocity, drawn from the point at which the particle meets the circumference, with a tangent to the circumference, drawn from the same point.

We shall now show the application of the foregoing principles to the designing of a wheel to utilize a given water-power. The example shown in Fig. 6094, which we take as an illustration, was designed to work the pumps of a lead mine, 80 fathoms in depth below the adit, and in which the quantity of water to be raised necessitated a motor of 20 effective horse-power. The total available fall was 25·5 ft., and the mean discharge of the stream, when not swollen by rains, was found to be 550 cub. ft. a minute. Thus the total power of the fall was $25 \cdot 5 \times 550 \times \cdot 001892 = 26 \cdot 5$ horse-power. Obviously, therefore, to make 20 of this horse-power effective, the wheel must give an unusually high percentage of work. As it was requisite that the wheel should have a velocity of 7 ft. a second at the circumference, the head required to bring the water upon the wheel with this velocity is 9 in. The value of h may therefore be taken as $9 \times 2 = 18$ in., and $H - h = 25 \cdot 5 - 1 \cdot 5 = 24$ ft. Applying the formula already given, we have $\frac{24}{1 \cdot 6} = 15$ = the radius of the wheel. The diameter of the wheel will thus be 30 ft. The circumference is $30 \times 3 \cdot 1416 = 94 \cdot 248$ ft. The number of arms being 8, 96 will be the nearest number divisible by the number of arms, and therefore 96 = the number of buckets. To carry the water down to the lowest possible point, curved iron floats are used, the length of the wrist being found as in No. 2, Fig. 6092, and the centre of curvature determined, as shown in No. 4, with an angle of 12°. The sectional area of a bucket is approximately 9 in. × 12 in., and as the buckets are not to be more than half full, we have $\frac{9 \times 12}{2} = 54$ sq. in. as the available area. The discharge of the stream is $\frac{550}{60} = 9 \cdot 16$ cub. ft. a second, and as the wheel has a velocity of 7 ft. a second, seven buckets will pass the sluice in that time. Hence we have $54 \times 7 \times x = 9 \cdot 16$ cub. ft. $= 15828$ in.; whence $x = \frac{15828}{54 \times 7} = 42$ in., nearly = the length of the bucket, and consequently the breadth of the wheel.

6094.



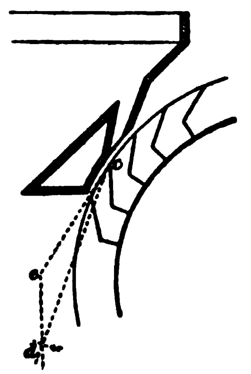
If the work of this wheel be calculated from the height of the loaded arc, as described above, it will be found to be about 80 per cent. of the total power of the fall.

The mode of applying the water to a wheel is a matter of great importance, and one which has not received its due share of attention. Instead of being directed into the buckets, in very many instances it is left to get in as best it can, and the tardiness with which it frequently enters under these conditions has rendered it necessary to give a longer radius of curvature to the fore parts of the buckets than would be requisite were more care taken in the application of the water. The angle of 12° which we have spoken of above, and which has been adopted in the foregoing example, we recommend only on the condition that the water is delivered in the most fitting manner, and it therefore behoves us to consider briefly this question.

When the wheel is overshot the orifice of the sluice should be brought as near as possible to the top of the wheel, and from this point a wheel-race should conduct it to the required point. This wheel-race should be slightly inclined, and its length should be such that, with the given head of water, the sheet may meet the circumference of the wheel in the direction best suited for a ready entrance into the bucket at that point. The thickness of this sheet should be less than the width of the opening between the buckets, and its breadth less than the length of the bucket by about 4 in., thus allowing 2 in. at each end for the escape of the air. The wheel-race ought never to be inclined more than $\frac{1}{16}$, and about half an inch play should be left between the end of the race and the wheel.

When the wheel is high-breast, the orifice of the sluice must be placed directly over the point to which the water is to be applied, and the sides of the orifice so disposed as to direct the water into the buckets. The method of finding the proper direction of the sheet is as follows; — At the point c, Fig. 6095, at which the water meets the circumference of the wheel, draw a tangent $c\,e$ to this circumference, and trace the profile $c\,b\,a$ of a bucket. Take the velocity v of the wheel as equal to ·66 of the velocity V of the effluent water, and mark off to any scale a length $c\,e$ to represent this velocity. Through the point e draw $e\,d$ parallel to the face $b\,c$ of the bucket, and from the point c, with a radius equal to V on the same scale, describe an arc cutting the line $e\,d$ in d. Join the points d and c. Then the line $d\,c$ produced will be the direction sought.

6095.



The line $d\,c$ shows the direction of the mean particle of the fluid vein; to find the directions of the sides of the orifice, repeat the construction 2 in. above and 2 in. below the line $d\,c$. The lower edges of these sides should terminate in a circumference concentric with the wheel, with a radius half an inch greater than that of the wheel. The breadth of the orifice should be less than the width of the opening between two consecutive buckets, and its length should be 4 in. less than that of the buckets, as in the preceding case, to allow the air to escape freely. When the water is applied to the

wheel from an overfall, the edge of the overfall must be determined in the same manner as the sides of the orifice described above.

See FLOAT WATER-WHEELS. HYDRAULIC MACHINES, *Varieties of.*

PADDLE-WHEEL. FR., *Roue à aubes ou à palettes d'un bateau à vapeur;* GER., *Ruder,* or *Schaufelradenies Dampfschiffes;* ITAL., *Ruota a palette;* SPAN., *Rueda de paletas propulsora.*

See MARINE ENGINE.

PAPER MACHINERY. FR., *Machine à papier;* GER., *Papier-Maschine;* ITAL., *Macchina da carta;* SPAN., *Maquinaria para la fabricacion de papel.*

The distinctive feature of hand-made and machine-made papers is, that whilst the former is made in separate sheets of limited sizes, machine-made paper, though limited in width, runs off from the machine in long rolls, frequently more than a mile in length without a break. Although the use of the machine is all but universal for ordinary papers, some of the more costly descriptions are still hand-made—drawing papers, for instance, and that known as antiquarian, which measures about 53 in. by 31 in., is the largest so made. Such is the quantity of liquid pulp required in the manufacture of a single sheet of this paper, that eight or nine men are required to manipulate it; whereas, when once the paper-making machine is in good working order, but little superintendence is necessary.

Of late years the demand for paper has developed to so great an extent, that the paper-makers' best stock—rags—has not been supplied in anything like sufficient quantities to meet their requirements. Much expense has been incurred, and great ingenuity has been displayed in attempts to utilize a number of other fibrous materials for the manufacture of pulp. Esparto grass, straw, and wood are now largely employed in the fabrication of pulp suitable for printing paper; bagging, canvas, and old rope are used for brown and other coarse papers, but hitherto no substance has been found to supersede, or even to satisfactorily supplement rags for the finer kinds of paper, such as writing and drawing papers. Weight for weight in the raw material, rags are far more costly than other substances employed; but when the waste in manufacture is taken into account, together with the cost of the various processes and the value of the produced pulp, the balance in favour of the recently-adopted raw materials is very much reduced. Whatever article is used for stock, it is only in the manufacture of pulp that the processes are dissimilar, for the pulp once obtained, there is no difference in principle involved in the machines which turn it into paper.

We have first to consider paper made from rags, and as the quality of the pulp depends upon the description and regularity of the rags employed, it is of the utmost importance that these should be carefully sorted and cleansed. In the rag-sorting room, which is usually in an upper floor of the mill, rows of tables are arranged, provided with boxes divided into numerous compartments.

The top of each table is covered with a wire-gauze sieve, and there is fixed an upright knife with its edge facing the sorter. Girls are usually employed for this operation. They take each piece of rag separately from the unsorted mass, tear and slit it into small fragments against the knife, remove all foreign matters, shake off the dust as much as is possible, and place the rag in its proper compartment.

Fig. 6096 is a ground plan to show the general arrangement of a paper-mill for two rag paper-making machines, Figs. 6097, 6098, longitudinal sections, and Figs. 6099, 6100, cross-sections of the mill. A, rag store-rooms; B, main building, consisting of three stories and attics; on the ground floor are placed rough rag-dusting room, rag-engine gearing, immersion boxes, and wet presses. On the first floor are the rag-engines and the rag-boilers, which are suspended with their gearing nearly over the alkali store; also the mixer for bleaching liquors, and stock cisterns with gearing driven from upright shaft. On this floor space is left for a large quantity of boiled rags stored in boxes or tanks, and for the store of half stuff from immersion boxes and gasing cells.

In the second floor are placed the rag-cutting, willowing, fan, and dusting machines, with the necessary gearing; at the end immediately over the rag-boilers, trap-doors or hatchways are cut in the floor, through which the boilers are charged with the prepared and assorted rags. The rags, both assorted and undusted, are stored in convenient receptacles both on this and on the third floor. On the third floor are the hand-cutting machines, and space for sorting and dusting the rags.

C contains the paper-making machines, with an engine to each machine. This is a long one-story building, with plenty of light, and a roof provided with ample means for ventilation; and arrangements should be made to carry off the steam from the machines, as, if it is allowed to collect, it will condense on the roof and drop down upon the paper in the machines, spoiling the roll in hand, and injuring the character of the mill for regularity in quality.

The machines must be erected on good solid foundations, and the floor should be laid with a gentle slope to allow all water to run at once out of the machine-room. To allow of easy access to the machine, and for the occasional removal of a roll for repairs, there should be a clear space on each side of the machine about 1 ft. wider than the machine itself; thus, a 6-ft. machine should be erected in a room not less than 20 ft. wide.

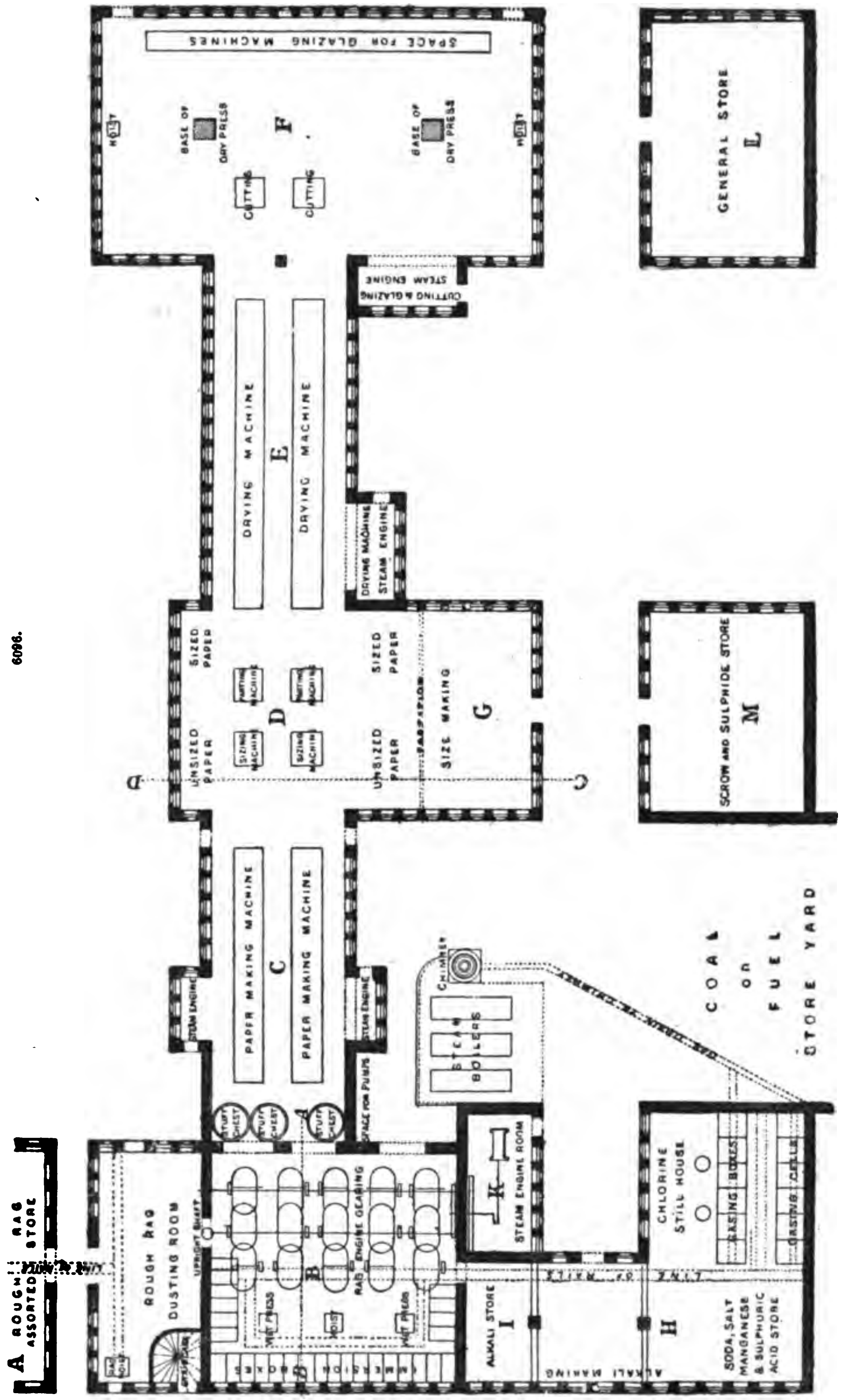
D, sizing and parting room, similar to C, but wider, to allow the stock of sized and unsized paper to lie a sufficient time after being made and sized.

E, drying-machine room, about the same size as C, with engine-room at the side, one engine driving both drying machines.

F, a two-story building, containing on the ground floor the cutting, glazing, and rolling machines, the base plates for dry presses, and hoists for the cut and glazed paper. The hoists are worked by a steam-engine, either separately or together, and lift to the upper floor which contains the dry presses, the general finishing apparatus, and the store of finished paper.

G, on the ground floor the size-making is conducted, which is lifted to the upper floor, a sufficient height to allow the size to flow freely to the sizing machine.

H, for chemical apparatus, is one story high, with ventilation in roof, and flue to convey gases to chimney.


SPACE FOR GLAZING MACHINES
F
BASE OF DRY PRESS
BASE OF DRY PRESS
HOIST
HOIST
CUTTING
CUTTING
CUTTING & GLAZING STEAM ENGINE
GENERAL STORE
L
DRYING MACHINE
E
DRYING MACHINE
DRYING MACHINE STEAM ENGINE
SIZED PAPER
UNSIZED PAPER
SIZING MACHINE
PARTING MACHINE
D
SIZED PAPER
UNSIZED PAPER
SIZE MAKING
G
SCROW AND SULPHIDE STORE
M
PAPER MAKING MACHINE
C
PAPER MAKING MACHINE
STEAM ENGINE
STEAM ENGINE
STUFF CHEST
SPACE FOR PUMPS
CHIMNEY
STEAM BOILERS
COAL OR FUEL STORE YARD
K
STEAM ENGINE ROOM
CHLORINE STILL HOUSE
BASING BOXES
CASTING CELLS
RAG ENGINE GEARING
B
WET PRESS
HOIST
WET PRESS
IMMERSION BOXES
UPRIGHT SHAFT
ROUGH RAG DUSTING ROOM
A ROUGH RAG ASSORTED STORE
ALKALI STORE
I
H
ALKALI MAKING
SODA, SALT MANGANESE & SULPHURIC ACID STORE

6096.

I, alkali store, on the ground floor. On the floor above, as before mentioned, are placed the rag-boilers.

K, engine-room for rag-engines, with steam-boilers and chimney at side. It is considered preferable to have several engines to drive the separate machines, rather than large engines communicating by long lines of shafting with the various machines. By this means the heavy cost of shafting and numerous drums is avoided; the machines may be worked to a great extent independently of each other, whilst if a convenient position is chosen for the range of steam-boilers, and the steam-pipes are carefully lagged, comparatively little power is lost.

L is a general store. M, store for scrow and sulphide. N, general shops and offices.

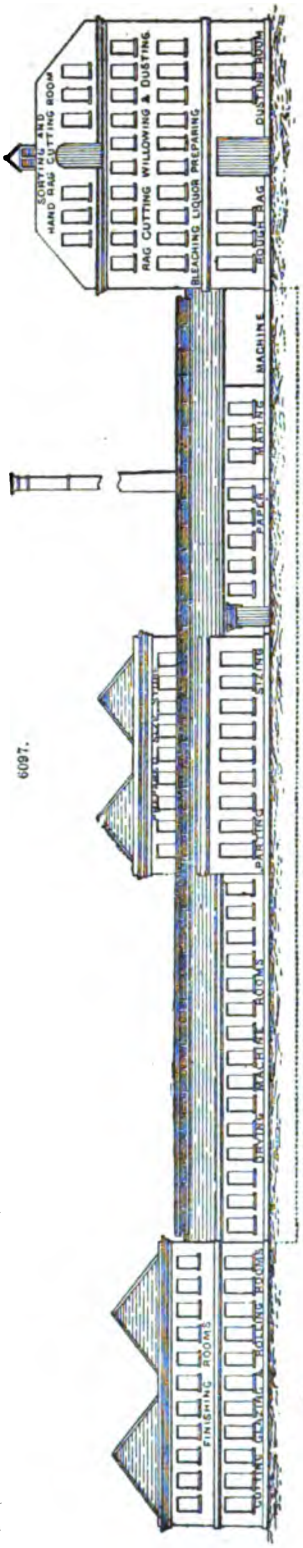
Dusting Machine.—The most simple apparatus consists of a truncated cone turning on the axis of the large circle, and on two pulleys working into a groove in the top of the small circle. The case is covered with a web of wire-work. The interior of the casing is furnished with iron teeth placed spirally, which force the rags to pass through the opening opposite to the inlet. A dusting machine of this kind is only suitable for fine, clean, and half-clean rags. Fig. 6101 is a rag-duster made after this plan by G. Tidcombe and Son, of Watford.

To render the action more forcible, there must be placed in the interior a shaft having iron arms arranged spirally. These arms carry the rags against the wire gauze, which turns inversely to the rotative movement of the shaft. This arrangement is preferable for very dirty rags, hems, seams, and the like.

When the dusting machine is cylindrical, it may have an inclination of 25° to 40°.

The devil serves for dividing and dusting the particles of linen, hemp, oakum, and ropes. Constructed on the same principle as the preceding apparatus, it offers a resistance in ratio with the work which it should produce. The iron axis fitted with spindles is alone movable, and the impurities fall upon the web of an iron frame.

The waste caused by the devil, sometimes very considerable, has caused its rejection in some paper factories. It much facilitates, however, the



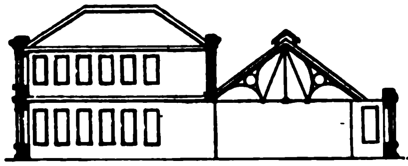
6097.

6098.

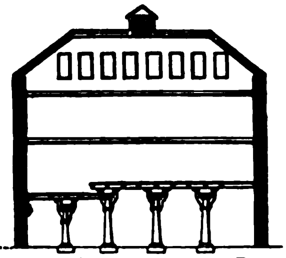
operation of washing, and the different other manipulations in disintegrating the fibres and rendering them suitable for undergoing the action of the leys. These rags thus softened are cut and torn with greater ease. It requires more power than any other rag-duster.

6099.

6100.

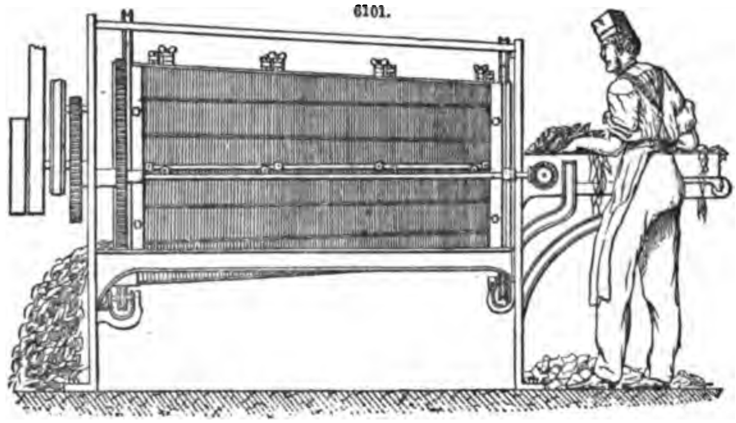


Section on line C. D.



Section on line A.B

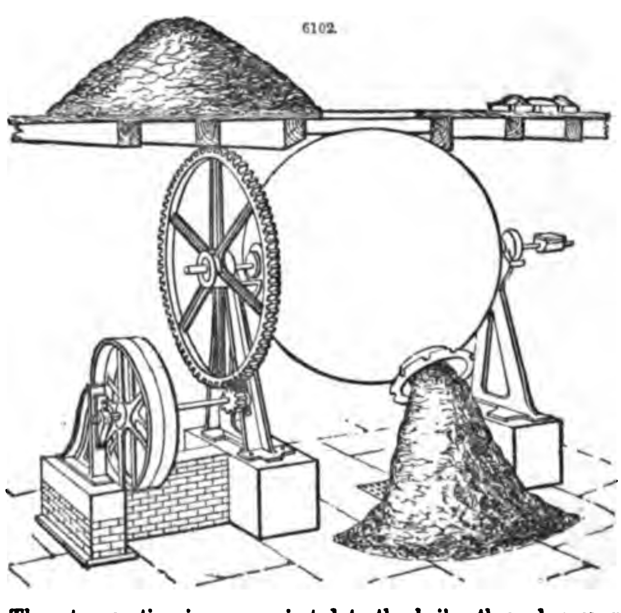
6101.



Whatever be the dusting machine employed, it is indispensable to enclose it in a frame cased in wood for localizing the dust and other impurities which, mixed with the fibres, are called dusting-machine waste. The quality of this waste varying according to the nature of the rags, it is important not to work on the same day a greater variety of rags than can be avoided.

B. Donkin & Co.'s Spherical Rotary Rag-boiler, Fig. 6102.—These spherical high-pressure boilers are made in wrought iron, about 8 ft. diameter. The plates are of the usual substance, but owing to its spherical form, the boiler offers twice the resistance to rupture which would be given by a cylindrical boiler of the same diameter, and made of plates of the same thickness. The spherical shape has also another important advantage; it allows all the rags to fall out by themselves when the boiler is revolving with its cover off. The boiler is mounted on a pair of trunnions, both of which are made hollow for the purpose of admitting steam and water. The rotary motion is communicated to the boiler through a spur-wheel keyed on to one of the trunnions. The flanges of the trunnions and the boiler are faced in the lathe, so that a good joint may be made with red-lead simply. Inside the boiler are lifters

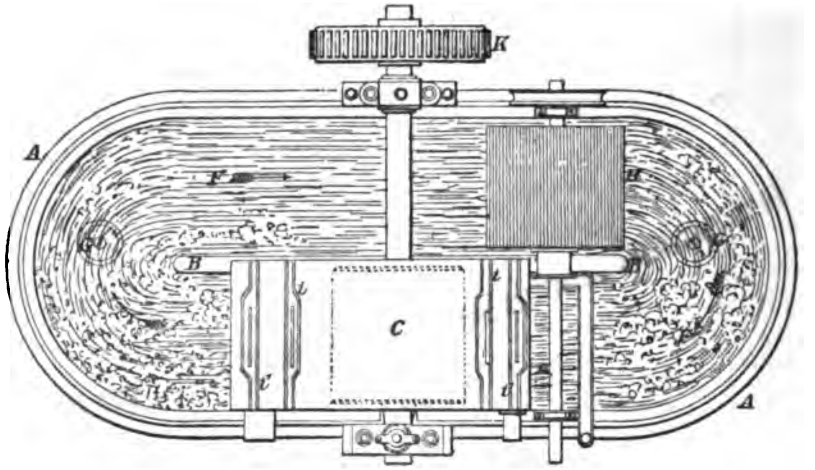
6102.



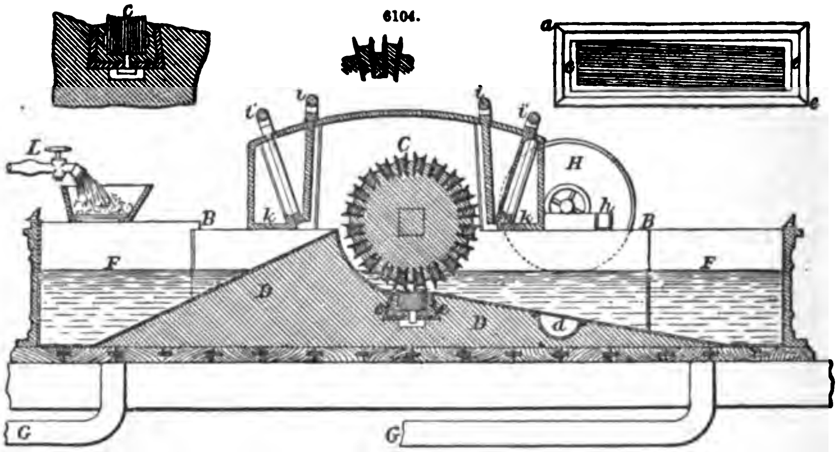
to agitate the rags as it revolves, and strainers to take off the dirt and refuse. The gearing by which the boiler is driven is proportioned so that the vessel makes one and a half revolutions a minute, with the shaft carrying the belt-pulleys running at seventeen and a half revolutions. Altogether the boiler stands about 11 ft. 6 in. high, from the floor-line to the top of the man-hole, and in practice it is usually mounted so that it may be filled through an opening in the floor overhead.

Washing Engines.—Formerly all dividing of the rags was performed by means of stampers or stocks, for which reason the machines for tearing, scratching, and refining, have got the name of rag-tearing, rag-scratching and washing engines, which they retain to this day. A modern washing engine, Figs. 6103, 6104, is a large box, A A, 10 ft. long, terminating at each end by a half

6103.



6104.



cylinder, composed of eight metal plates, bolted together on a wooden foundation; a vertical diaphragm B B, placed lengthwise, divides it into two troughs, leaving at the ends a space as large as each trough F F, in order that the rags may continually circulate from one channel to another, according to the movement of the liquid obstruction.

In the middle of one of the divisions, and perpendicularly with the diaphragm, is adapted on cushions the axis of a cylinder C, furnished with blades, which are arranged in pairs and retained in their grooves by wooden wedges between each; underneath this cylinder is laid a metal plate *e e*, a kind of frame filled with blades *c*, which are bolted together and tightly fixed by wooden wedges run in with lead; these blades, thirteen in number, are parallel to each other, and form a slight angle with the blades or the axis of the cylinder; this axis, more or less horizontally raised with the aid of a double adjusting screw, leaves an interval which is gradually diminished as the rags are divided, the distance varying according to the degree of division which is to be obtained. The cylinder is turned about from 220 to 240 times a minute, and thus determines the velocity of the water, which thence circulates into the engine; the rags, forced away by this current, pass and repass continually between the cylinder and the plate, where they are divided. The washing is also completed in the engine at the same time that the tearing and scratching of the rags is effected,

and as the water must be incessantly renewed, a continual current of limpid water is introduced into the engine by a cock L furnished with a woollen sack, and pouring upon a sieve. After the rags are washed, the water flows away by two wire-gauze frames i^1, i, placed before and behind the cylinder, into the drains k bordering on an ordinary discharge-tube. When the greatest part of the turbid water is thus extracted from the half stuff, there must be placed before the two frames with wire gauze the two plain wooden shutters i, i. Sometimes there is arranged in the engines, on the second trough, a washing cylinder furnished with a wire gauze H, turning freely with a velocity of about twenty revolutions a minute, under the influence of the current which affects, in the other trough, the tearing cylinder; this cylinder, whilst opposing the passage of all fibres, allows the liquid to enter its interior. The water which has entered the washing cylinder is taken again by tubes of spiral form bringing back the liquid in the axis and letting it pass out through the drain h h^1 above the engine; the drain d covered with a lattice retains the sand and other heavy bodies.

A toothed wheel K, or in some cases a pulley, communicates the movement to each cylinder of the engines for tearing and refining; these cylinders have generally forty-six blades jointed in pairs, and the refining engines fifty-one blades arranged by threes.

L. C. Stuart's ingenious pulper, Figs. 6105 to 6107, consists of a cylinder closed at each end, containing a revolving disc of nearly as large diameter as the interior of the cylinder within which it revolves, and the disc is of such thickness as to leave a small space between each of its two side surfaces and the two end covers of the cylinder. The surfaces of the disc and of the interior of the cylinder are formed with grooves, or with teeth, to aid in the grinding process. The disc receives a quick rotary motion, and there is provision made for the disc to move a small distance to and fro within the cylinder.

The stuff is fed with water from an elevated reservoir or cistern into the cylinder at one end towards the centre, and by reason of the source of supply being elevated, there is a proportional hydraulic pressure. The pulp flows off from the other end of the cylinder through a pipe, which can be more or less elevated, by which the speed of flow through it may be regulated, and the stuff kept for a longer or shorter time under the grinding process.

Several serious defects existing in the ordinary stuff engine are obviated in this machine, by providing for the withdrawal of the fibre from the action of the grinder the moment it is sufficiently reduced, and leaving to be longer acted upon that which requires more grinding, by which means the whole of the fibre, whether strong or weak, is reduced to pulp of uniform fineness, each part of it being subjected to a degree of grinding proportioned to its strength; whilst by rendering the feed independent of the motion of the grinder, the engine can be run at any speed that its strength will sustain, and the work is done much more rapidly than in the old engine. By dispensing with the annular vat, and feeding the stuff to the engine through a pipe, and discharging the pulp by similar means, this engine is rendered very compact, and requires far less space than that occupied by the engine heretofore in use. To suit various kinds of stock, the grinder adjusts itself as required; this is accomplished by having a revolving grinder placed between two stationary grinders, the revolving grinder having play on its axis to enable it to move freely to and fro between the stationary grinders as required; the fibre to be ground being caused to pass in a current through the spaces between one stationary grinder and one side of the revolving grinder, thence round the periphery of the revolving grinder, and through the space between the opposite side of the revolving grinder and the other stationary grinder to the orifice of discharge.

As in grinding rags or other fibre to half stuff, or in reducing half stuff to pulp, it is important to vary the rate at which the fibrous matter is fed through the grinder, while the motion of the grinder remains constant, the feed is rendered adjustable by varying the level of the nozzle of the discharge-pipe relative to the level of the head of water in the feed-pipe; the effective head of feed pressure is thus varied, and as a matter of course the velocity of the feed current is correspondingly varied.

The fineness of the grinding, it will be seen, depends upon the hydraulic pressure on the feed and the speed with which the disc of the grinder runs, while the rate of feeding depends upon the hydraulic pressure. In case a knot of fibre should be fed into the grinder, the disc would yield, moving towards the side opposite the knot, to allow the knot to pass freely towards the periphery, where it would quickly be reduced by the energetic action of that part of the grinder. While this reduction of the knot is going on at the feed side of the grinder, both the feeding and the discharge are diminished by the forcing of the revolving disc against the discharge orifice. If the fibre is easily reduced, it will flow freely through the grinder, and occupy little more space on the feeding than on the discharge side of the disc; but if the fibre is tough and grinds slowly, it will accumulate on the feed side, and force the disc to the discharge side, retarding the discharge, the strong fibre being in this way subjected, as it requires, to more grinding action than the weaker fibre.

The pump is supplied from a stuff chest through the suction-pipe A, Fig. 6105; it discharges into the sliding shoot B in the feed-hopper. This shoot is for regulating or shutting off the supply to the beater as required. The feed-pipe conveys the stuff to a point near the centre of the disc, and after it is beaten it passes off by the pipe E. The disc C has ribs or projections cast into both its faces placed in the manner shown; one side works truly against a fixed plate with similar knives in it, and the other side against a plate which is fixed to the screwed cylinder D, and is adjusted by means of the hand-wheels L, L.

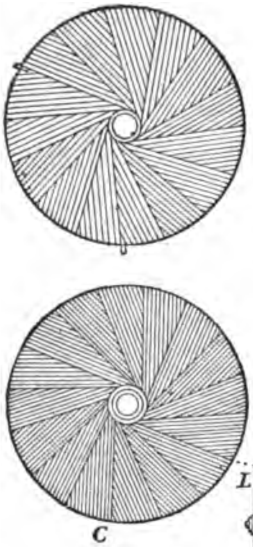
The beater, as supplied by Easton and Anderson, of London, requires only to be bolted firmly down to a foundation, as most convenient; and the pump, with the other adjuncts, has to be fixed as shown on the drawing.

The first thing to be done after mounting, or after new disc or plates have been received, is the setting and facing of the working surfaces, which is performed as follows;—

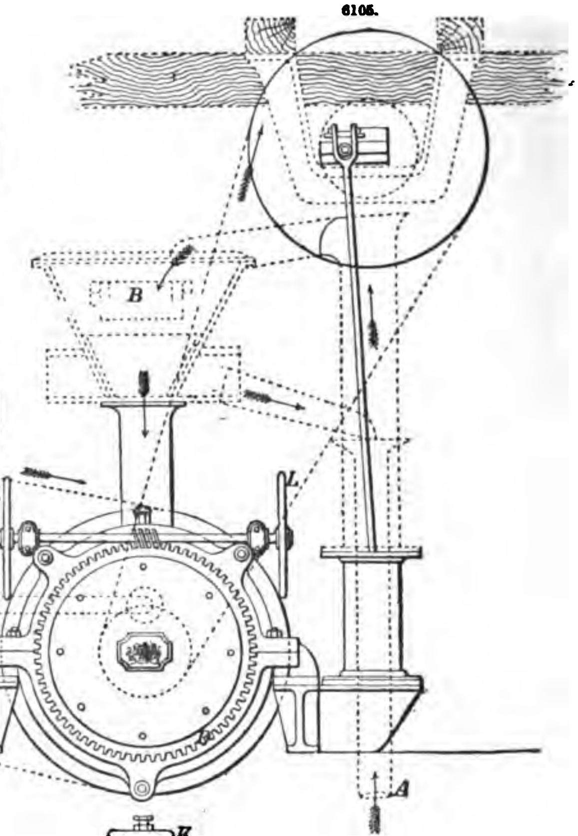
Before starting, the tail-screw K must be screwed back, and the four working surfaces set close home, one on to another, by the front set L; the tail-screw K must then be screwed forward until

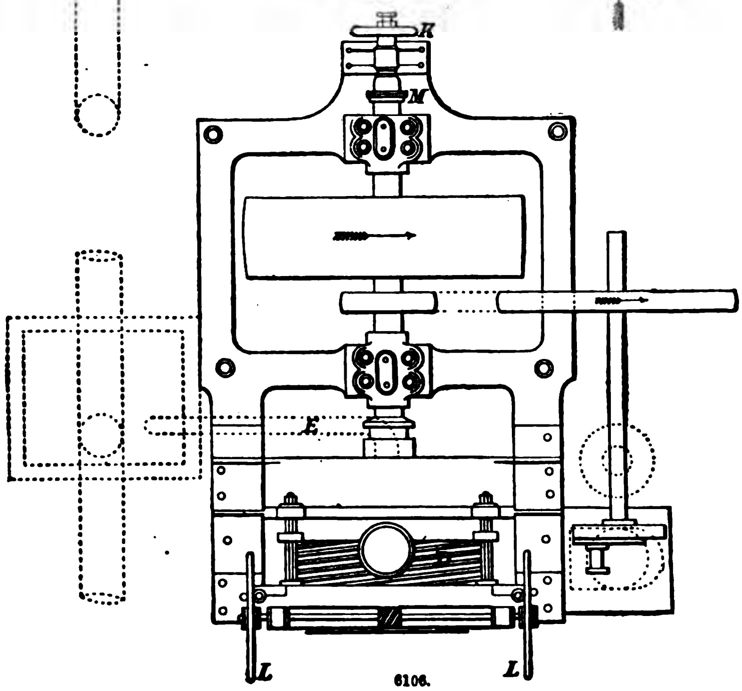
it touches the end of the shaft M, and in that position must be secured by the locking handle. The four working surfaces must then be brought out of contact by slacking back the front set L, and the

6107.



6105.





6106.

beater started. By slowly setting up the front set L, and thus screwing the surfaces into contact, running water through the machine all the time, the facing and surfacing will be accomplished, and, in order that the finishing sides may come into contact for this purpose, the tail-screw K must be gently eased. The sound produced will soon show how far the grinding has advanced, but it will be prudent to take out the surfaces, and judge by actual inspection whether they are to a fair bearing all over. This surfacing operation will ordinarily occupy rather less than one hour.

The beating engine is filled in, the bleach washed out, the size and colour added, the roll being down in the ordinary manner. By the time the admixture of the whole is complete, the engine may be emptied into the reservoir chest below. Three ordinary beating engines, filled and emptied alternately, will be kept fully employed in this operation.

Before starting, the surfaces ought to be set in the same manner as in grinding; that is to say, the tail-screw K must be screwed back, and the four working surfaces set home by the front set L, the tail-screw set to the spindle end and locked, exactly as there described. After bringing the surfaces out of contact by slacking back the front set, the beater may be started; but it is necessary to have the sliding shoot B in the feed-box so placed that the stuff may for some minutes pass away to the overflow without entering the beater. By this time the stuff will have become thoroughly mixed in the circular chest, and all else being ready, the sliding shoot may be reversed and the flow from the pump turned direct into the feed-box, and so into the beater. The working surfaces must then be screwed up by the front set L, and regulated until the requisite sample of pulp is produced, which may be readily ascertained at the discharge nozzle.

On no account must this regulation be attempted by altering the tail-screw K, as it is essential that the back or finishing surfaces should be in contact, but so guarded at the same time by the tail-screw, that no force applied at the front set could possibly bring them in closer proximity. The adjustment of the tail-screw can only be properly accomplished when the beater is standing, and the machinery stopped for oiling, &c., say, once every twelve hours.

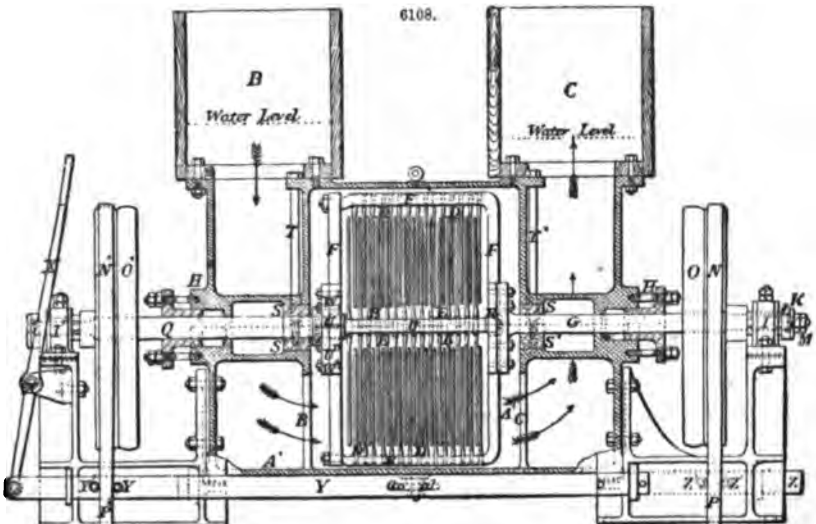
In stopping, the sliding shoot must be set to pass away the stuff to the overflow, as before mentioned, the grinding surfaces relieved by slacking back the front set, washing through with a stream of water at the same time.

The tackle should not be allowed to run on after becoming thoroughly dull, as the work produced will be unsatisfactory, and the loss of power very great; under such circumstances, the spare set, which should always be kept sharp and in readiness, should at once be put in, which will occupy but a short time, and the dull set prepared for the next change of plates at leisure.

Easton and Anderson, who make this machine, have found that it produces a thoroughly even and continuous supply of pulp.

E. A. Cowper's new arrangement of pulper avoids the peculiar cutting action of Stuart's pulper, acting more on the principle of opening and separating the fibres, and is therefore preferable where it is of importance to retain the pulp fibres of their full length. It is especially suitable for pulp from wood, straw, or esparto. It consists of a closed cylindrical vessel, having at one end an inlet by which the fibrous material to be separated is introduced with a regulated proportion of water, and at the other end an outlet for the water with the separated fibres suspended in it. A shaft passes through a stuffing box in the centre of the one end of the vessel, and another shaft likewise passes through a stuffing box in the centre of the other end. On one shaft are fixed a number of radial bars, and on the other shaft is fixed a frame which can revolve outside these radial bars, and from which a number of radial bars project inwards, the two sets of radial bars being arranged so as to pass clear of each other. The two shafts revolve in opposite directions, so that their bars, moving through the liquid in the vessel, produce powerful opposing currents, which, dragging the fibres in different directions, separate them from each other without breaking them.

6108.



The speed of working may be such as to produce the powerful currents required to tear asunder the masses of fibre, the vessel being closed. The contained liquid while agitated by opposing currents is not made to rotate bodily, and the operation is rendered continuous, the materials to be operated on being introduced in a regular stream at the one end of the apparatus, and the liquid with the pulp uniformly distributed through it issuing at the other end.

Fig. 6108 is a longitudinal section of this apparatus. A, A^1, are two halves of the cylindrical case of the apparatus; B B is the inlet for the fibrous materials to be separated, and for water; C C is the outlet for the water, with the separated fibres suspended in it after having been acted on within the cylinder. The radial bars D, D, are attached to the frame F fixed to the shaft G, which passes through the stuffing box H, and is at its outer end carried in the bearing I. The end of the shaft G is provided with a screw J passing through a collar K set with a feather L on the shaft G, so that it must turn therewith, but can slip longitudinally thereon. Nuts M on the screw J regulate the position of the shaft G, and the one set of bars D attached thereto in relation to the other bars E. The shaft G is provided with fast and loose pulleys O and N, so that it can be driven by a strap P carrying round the radial bars D, D. The other radial bars E, E, are attached to the shaft Q, one end of which is steadied by the brass bush R in the end of the shaft G. The shaft Q passes through the stuffing box H^1, and is supported at its outer end by the bearing I^1, and is provided with means of longitudinal adjustment, as described, for the shaft G. The shaft Q is also provided with fast and loose pulleys N^1, O^1, by which it is driven by a strap P^1 in the opposite direction to the shaft G.

In order to take up any shake which may occur owing to the wear of the brasses S, S^1, screws T, T^1, are provided, tapped into the bottom brasses S^1, S^1, and having their ends resting in holes in the casing of the gland, so that by turning the screws T, T^1, the bottom brasses S^1 can be raised.

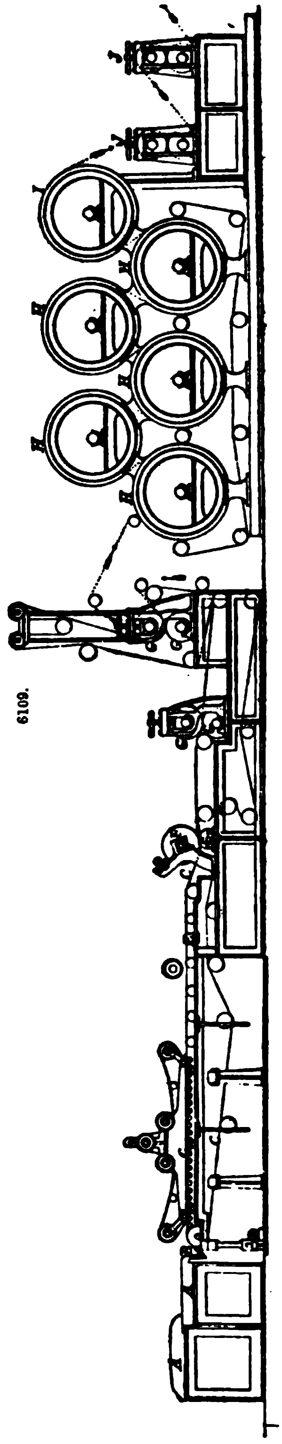
The end of the frame F is bushed with brasses U, U^1, to turn on the shaft Q. The two half-brasses U, U^1, which embrace the shaft Q can be drawn close together by screws V, V^1; the bolts W, W^1, which pass through slotted holes, being temporarily unscrewed to allow of this adjustment.

The apparatus is stopped or started by shifting the bands P, P^1, to the loose or fast pulleys. For this purpose X is a hand-lever turning on the fulcrum X^1, and connected at its lower end to a sliding bar Y, which carries two pins Y^1 for shifting the strap P^1; Z is a similar bar carrying two pins Z^1 for shifting the strap P; a is a lever pivoted at a^1 in its middle, one end of which works in a slot in the sliding bar Y, and the other end in the sliding bar Z. Thus by moving the hand-lever X the straps P and P^1 are shifted together.

According to the fineness or coarseness of the material to be acted on, the radial bars should be placed close together or farther apart to attain the desired action.

If it is desired to use this machine as a mixer or conditioner for different kinds of pulp, it is only necessary to feed the requisite proportions of pulp into the feeding inlet, and after passing through the machine they will be found to be thoroughly mixed and in good condition for the paper machine.

Paper-making Machine.—Fig. 6109 is a longitudinal section of a paper-making machine, as made by G. Tidcombe and Son, of Watford. Such a machine is capable of producing 5 tons of printing paper in twenty-four hours, but the amount of work performed varies according to the quality of paper required and the nature of pulp employed. Pulp being made of the required consistency, is stored in a reservoir conveniently placed near the strainers A, A. It is there mixed with a sufficient quantity of water to hold the pulp fibres in suspension, and cause it to flow freely into the knotters or strainers A, A. The pulp passes through the sieves, leaving behind it all knots and impurities. In old-fashioned machines the pulp merely passed along over the knotters, and was shaken through, leaving the knots on the surface, and the slits or spaces soon became choked. In order to clear them they were scraped, and much of the refuse was thus forced through the machine into the clear pulp beneath, and passed along with it to the paper-making machine. This operation had to be performed every two or three hours; thus much dirty and inferior paper was produced, and no regularity in quality could be obtained.

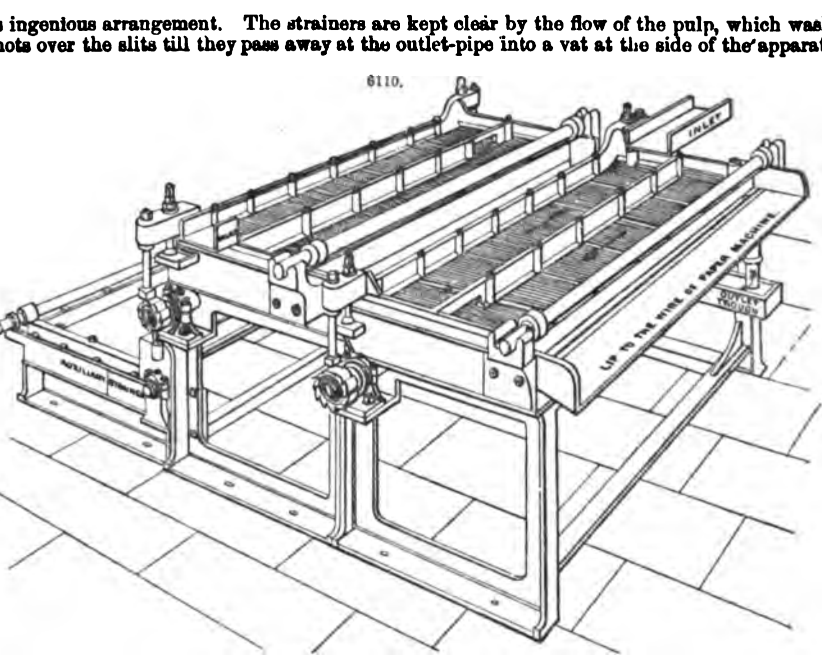


6109.

W. Ibotson, an English paper-maker, invented the strainer, now in universal use; this machine, shown at Fig. 6110, avoids all waste of pulp and irregularity in the quality of the paper

by its ingenious arrangement. The strainers are kept clear by the flow of the pulp, which washes all knots over the slits till they pass away at the outlet-pipe into a vat at the side of the apparatus,

6110.



whilst the clean stuff runs directly through the slits, and thence to the lip of the paper-making machine B.

The stuff is thence led over the travelling web of wire cloth C C C, Fig. 6109. This endless web runs over the small rollers or table D D D, and the vacuum-box E; this has a top of gutta-percha or vulcanite, or such material as will not wear the wire cloth, and which can be pierced with suitable holes through which water can be drawn. This box is in communication with a set of exhaust-pumps which draw the water from the pulp above the wire web, and this is the first process of extracting water from the stuff, excepting that which runs from it between the rollers D, D, D. The pulp or fibres are thereby felted together and form paper in a wet state.

During the passage of the stuff farther on, it will be observed that it passes between the rollers F, F. These rollers press it while on the wire, and this pressure is a further process of drying the wet paper by squeezing more water out of it. It receives another pressure in the same manner at G, G, and here the Fourdrinier paper-making machine really terminates.

The paper has next to be dried, and the speed and accurate timing of this portion of the apparatus regulates the quantity and quality of the paper produced; if the cylinders are driven too quickly, the fibres will not be well felted together, the paper will be too wet, and all the care employed in the previous operations will be thrown away.

A web of paper contracts in drying, and the amount of contraction must be allowed for in the proper graduation of the diameters of the drying cylinders, particularly if the stuff is composed of some of the new materials, such as straw, esparto, or wood. Rag-paper is not so variable as paper made from these new materials, because it has more elasticity.

The paper is conducted round the iron cylinders H, H, by travelling webs of felt, which sustain it and cause it to hug them so as to give an ironing effect—similar to a woman ironing linen—during the process of drying. These cylinders are about 4 ft. in diameter, and are heated by steam-pipes at their centres, which pipes are stationary, and the cylinders revolve round them. The pressure of steam is graduated by suitable feed-valves, giving generally most heat to the last cylinder I.

After drying the paper that is to be made for printing purposes, it is passed through polished iron calenders or glazing rolls J, J, to be glazed, and from thence to be reeled ready for the machine to slit and cut it into sheets. But if the paper is to be used for writing purposes, it is necessary to pass it through a bath of animal size or glue immediately after it leaves the drying-machine cylinders. This animal size gives it a parchment character. After passing through such a bath, it has to be dried gradually by hot air and fans instead of passing over hot-iron cylinders, so as to prevent curling or wrinkling, which such paper is liable to if dried too quickly.

Fig. 6111 is an enlarged view of the press rolls seen at G, G, Fig. 6109.

Fig. 6112 is a sectional view of the arrangement of the drying and cooling cylinders adopted by G. Tidcombe and Son. By the arrangement of graduated and properly-fitted cylinders for these operations, much waste, in the form of broken webs of paper, is avoided.

When more cylinders are used, some of them fitted with movable doctors, there is a great diminution in the destruction of felts. More drying surface also enables more paper to be made with the same amount of skilled labour, and the machine-men work better with the increased facilities.

The cylinders are regulated to precision, whether fitted with circular frames or otherwise, and the system of steam feeding is equal and certain. The scoops for emptying the cylinders form part

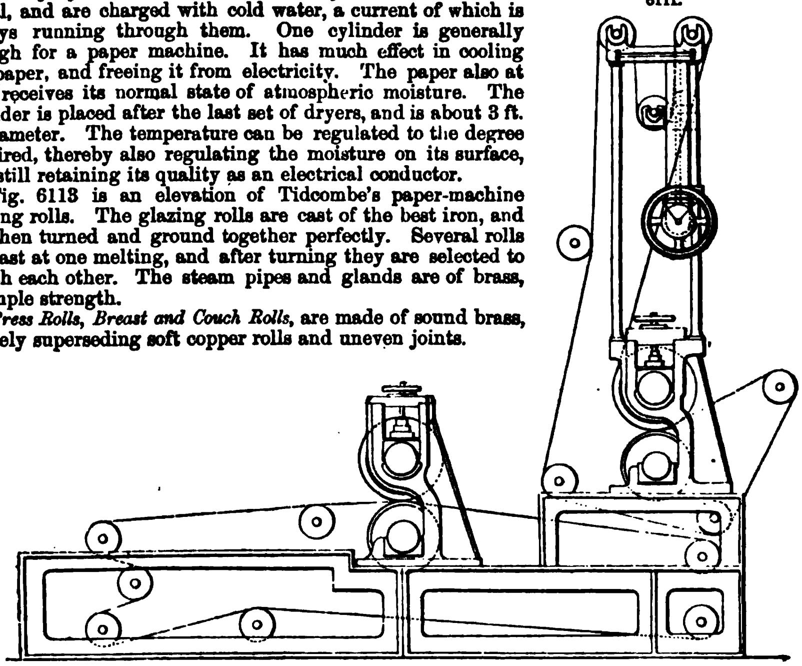
of the cylinders themselves, so that they cannot get loose, and cause danger and annoyance, and their fittings have ample room to discharge the condensed steam.

Cooling Cylinders and Electrical Dischargers are made of thin metal, and are charged with cold water, a current of which is always running through them. One cylinder is generally enough for a paper machine. It has much effect in cooling the paper, and freeing it from electricity. The paper also at once receives its normal state of atmospheric moisture. The cylinder is placed after the last set of dryers, and is about 3 ft. in diameter. The temperature can be regulated to the degree required, thereby also regulating the moisture on its surface, and still retaining its quality as an electrical conductor.

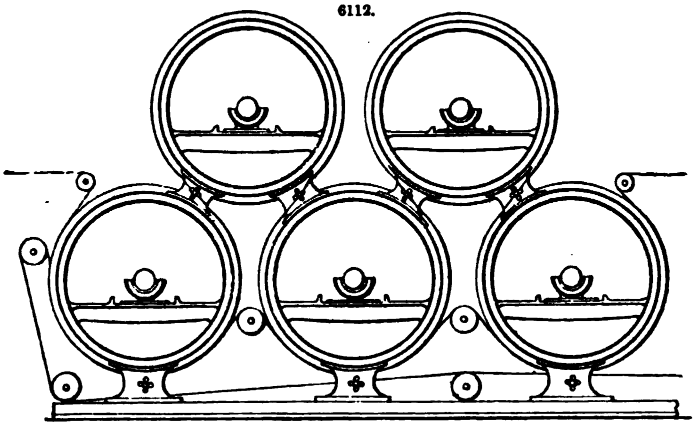
Fig. 6113 is an elevation of Tidcombe's paper-machine glazing rolls. The glazing rolls are cast of the best iron, and are then turned and ground together perfectly. Several rolls are cast at one melting, and after turning they are selected to match each other. The steam pipes and glands are of brass, of ample strength.

Press Rolls, Breast and Couch Rolls, are made of sound brass, entirely superseding soft copper rolls and uneven joints.

6111.



6112.



Iron Felt Rolls.—These should be made as light as possible, and properly fixed in their spindles to keep them from getting loose.

Guide Rolls, for guiding the wire, or for reeling the paper solidly and truly on the reels, should be properly proportioned and evenly made of brass, having adjusting carriages and screws.

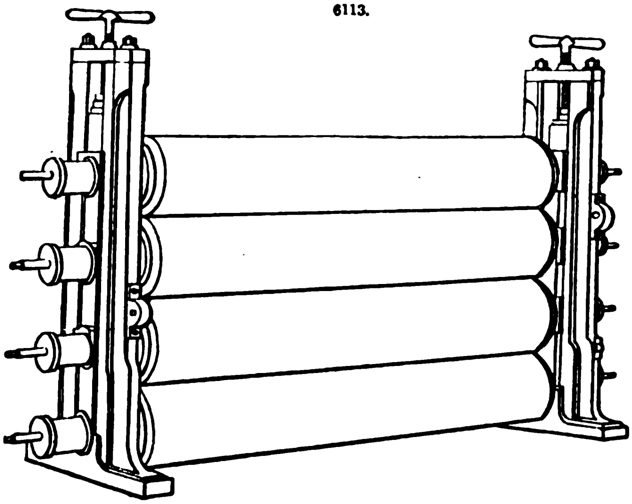
Tidcombes have introduced several improvements in their press rolls and accessories. They cover the press rolls with brass, and the upper ones have movable doctors, as shown on the section, Fig. 6111.

Fig. 6114 is of a reversible rolling and glazing machine, also by G. Tidcombe and Son. In this efficient machine much time is saved by the use of reversing gear; and as the latter is placed at an angle, the pack of paper is more easily fed into the rolls than in ordinary machines. The levers and weights are self-adjusting, and when extra pressure is required the machine can be fitted with another pair of compound levers having their weights near the ground.

Paper-cutting Machine.—Paper can be cut very economically and in a regular shape during its making, in several widths; it is sufficient to interpose between two of the drying cylinders, as in Figs. 6115, 6116, three, four, or five pairs of mechanical scissors, formed of double discs, *a f*, *b g*, and so on, sharpened with circular barrels, and rubbing on their flat sides. Each pair of discs effects a rectilinear section as the sheet of paper passes between them. A, B, C, D, Fig. 6115, are

shafts to which the cutting discs are fastened; E, E, standards; *o*, *m*, adjusting screws; and *x*, *y*, pulleys.

6113.



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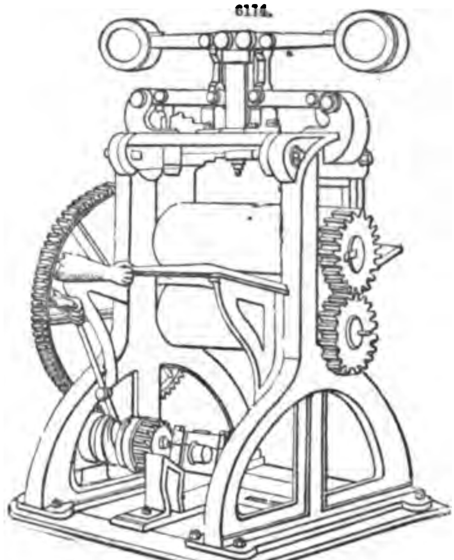

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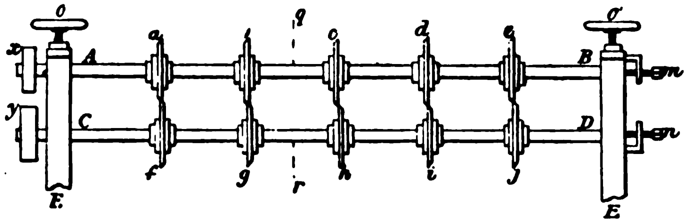

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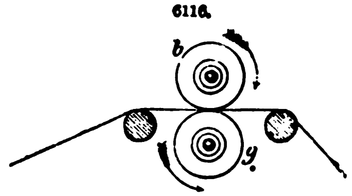


Section through q.r

6117.

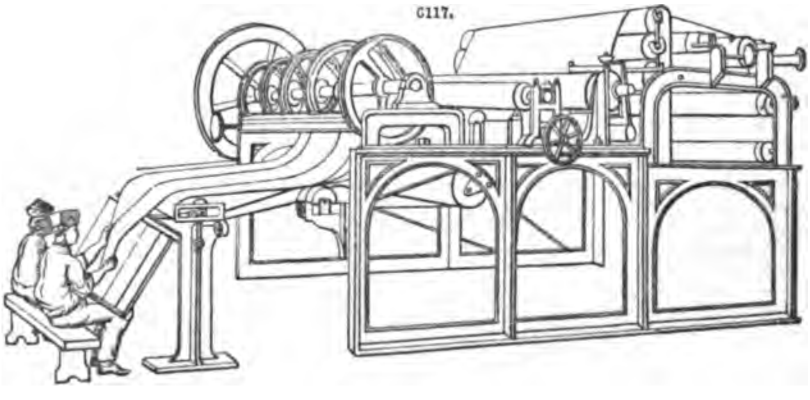


Fig. 6117 is an elevation of Tidcombe's detached paper-cutting machine. Its novel feature is the driving apparatus, consisting of short cone-drums, by which the lengths of the sheets of paper are regulated. By turning a hand-wheel one of the driving pulleys is expanded and the other contracted at the same time, thus giving double the range of speeds to the paper than by merely altering the diameter of one pulley. These alterations are made by the united movement of a right-hand thread on the shaft of one pulley, and a left on the other, in connection with cones that move into and expand the segments of one and retire from and contract those of the other. By thus altering the diameter of each simultaneously, a saving of time as well as paper is effected, and a less number of the ordinary change-wheels is required. They are driven by an *endless belt*, which works evenly.

Ibotson's Self-clearing Strainers.—Fig. 6110 shows two Ibotson's strainers, suitable for a 72-in. paper

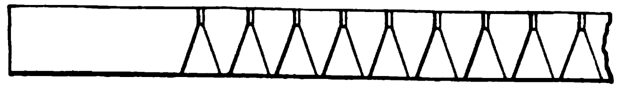
machine. They are fitted with Tidcombe's hard-rolled toughened plates. The pulp enters at the inlets, one being shown on each side in this double arrangement. The pulp takes the direction indicated by the arrows, the finer portions, filtering through the strainers, proceed at once to the lip—to the wire of the paper machine; the knots, lumps, or impurities, are carried along by the current over one set of strainers, through the opening in the partition, and back along the other set of strainers, and pass down a pipe leading to the outlet-trough, and thence to the auxiliary strainer, placed at the back of the machine. The necessary motion or jog is given to the strainers by the ratchet-wheels keyed on the shaft under the machine.

It will be seen that with this machine there can be little actual loss of pulp, as the back-water from the wire, mixing with the knots and impurities in the outlet-trough, flows back to the auxiliary strainer, which separates all the remaining useful pulp, rejecting only the actual refuse.

The strainers can be easily removed to be cleansed, and as the plates are perforated with slits of different sizes, the machine can be made to act perfectly well with pulp of various kinds and qualities by changing the strainer.

Fig. 6118 is a section of one of Tidcombe's hard-rolled toughened strainer-plates. The angles of the grooves and depth of the slits have to be regulated with great nicety for various descriptions of pulp.

6118.



The increasing demand for paper, and the impossibility of obtaining sufficient rags, having drawn attention to the possibility of producing good serviceable paper from other materials, has thereby opened up a nearly new industry, to which every day some improvement or addition is being made.

Hitherto straw, esparto, and wood have been the chief raw materials employed, but doubtless other articles in the vegetable kingdom will ere long come into use for the manufacture of paper pulp. Naturally the demand for paper is greatest in those countries which are the most densely populated, where labour is expensive, and where wood, straw, or esparto are comparatively scarce.

Esparto, which is grown principally in the south of Spain and north of Africa, is every year getting more and more scarce. Norway and Sweden produce wood in abundance, and labour is also cheap there; the demand for paper for home consumption is limited; but mills have been lately erected in those countries, and large quantities of pulp are made for exportation from wood, both by Voelter's grinding process and by the boiling process with chemicals.

The greater part of the pulp thus made is exported as half stuff, that is to say, after it has been through the washing engine it is dried by centrifugal machines or presses, in separate layers or cakes, which are tied in bundles and packed for shipment.

On arriving at the paper factory these cakes are broken up, mixed with water, and thoroughly pulped in the beating engine, after which the pulp is passed over a strainer, and is ready for the usual paper-making machine, or it may be mixed with certain proportions of other and finer pulp.

Straw pulp is seldom used by itself, as it produces a very short, crisp, and brittle paper; but with the admixture of some rag pulp it is much used for the manufacture of printing paper. Nearly all the straw pulp used in England is of home make. The machinery employed requires no special notice, as the straw after being cut up is treated in a similar manner to rags, the only important variation being in the strength and quantity of the chemicals required for the boiling process.

In connection with the boiling of pulp at high pressure, the improvements recently invented by Edward A. Cowper must be mentioned, as their tendency to save time and fuel is indubitable. By his arrangement of feeding the pulp-boilers through intermediate boxes containing charges of hot-soaked wood, Cowper avoids the cooling down of the boiler, hitherto necessary after each boiling, whilst by the arrangement of the furnace he protects the boiler from the damaging effects of a fierce fire directly impinging upon a comparatively weak surface as hitherto practised.

Fig. 6119 shows a vertical section of a pulp-boiler and setting.

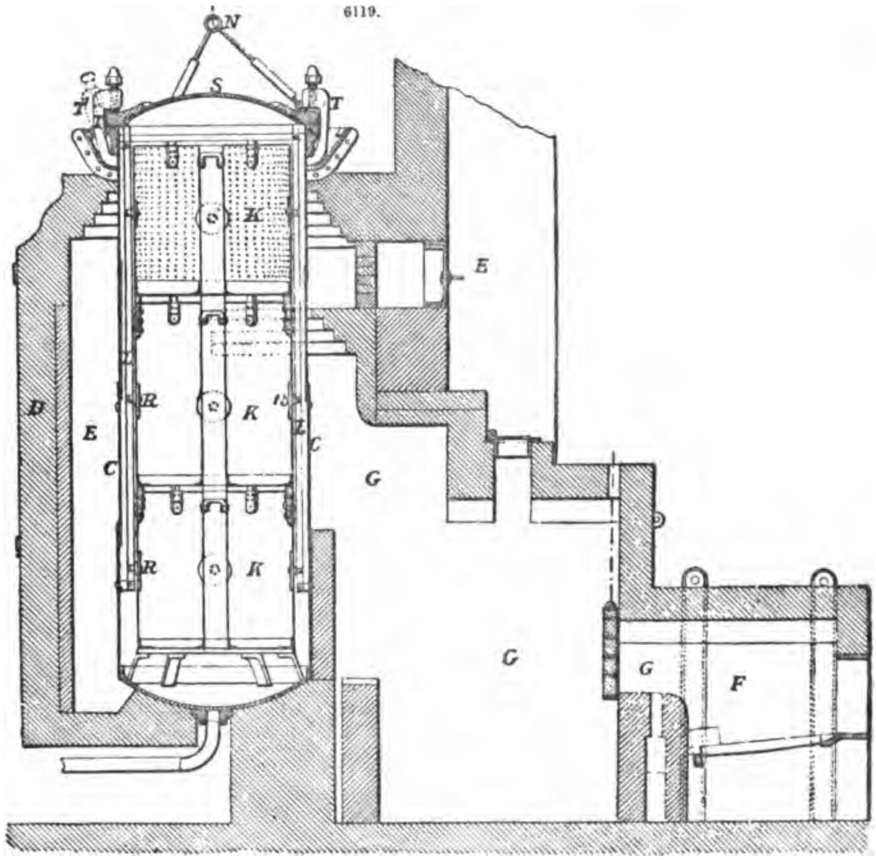
The pulp-boiler C C is set upright in brickwork D D with flues E, E, around it, so that the heat derived from a furnace F placed at a distance from the boiler may pass around the boiler till it enters the chimney E'. There is but a very small portion of the brick-setting in contact with the boiler, so that there is no danger of the brickwork, if hot, burning the boiler if empty. The flue G G G, immediately on leaving the fire F is greatly enlarged, so that by the time the heat comes in contact with the boiler, the area it acts upon is many times the area of the fuel at the fire, so that the boiler is only subjected to a mild heat, such as it can well sustain without injury.

The time of filling and emptying a pulp-boiler generally occupies a considerable portion of the total time of working a charge, and the heating up of the contents of the boiler to the boiling point also occupies considerable time, and if the material is a compact material like wood, and has not been thoroughly soaked with caustic alkali before it is put into the boiler, much time is lost, as it takes several hours for the whole to become perfectly saturated, and this evil is exaggerated by any variation in the compactness of the material being acted on. In order therefore to fill and empty a boiler quickly, to charge it with materials as hot as possible, to ensure their being acted on equally, and to reduce the time that the materials must remain in the boiler to be thoroughly cooked, a number of perforated boxes K, K, are placed in such a manner that they may be guided down into the boiler into their proper positions when lowered down by a crane, and remain truly in position in the centre of the boiler, there being guides L, L, fixed inside the boiler for the purpose; the crane-chain N is provided with a spring catch to which a light chain or cord is attached, so that when a box has been lowered down, the catch, which takes hold of a cross-bar fixed in a central tube in the box, may be released conveniently, although at the time it may be quite impossible for the workmen to see at all inside the boiler in consequence of the steam.

Previous to placing the boxes K into the pulp-boiler, they are filled with the material to be

operated on, and are then placed in a soaking tank nearly filled with strong hot caustic alkali, where they remain some time until well saturated with the alkali. after which they are conveyed

6119.



direct to the pulp-boiler C thoroughly hot, and ready for receiving the still higher temperature that they are subjected to when the boiler is closed and the cover screwed down tight, and heat is applied to the boiler, which is nearly filled up with caustic alkali, or water, or spent ley, and the valves of the boxes are kept closed until the whole has been raised to the required temperature, so that the caustic alkali may act on the material at the high temperature without dilution. The valves of the boxes are afterwards opened so as to allow the liquor in the boiler to circulate through the material in the boxes. The cover S of the boiler is secured by a number of screw-clamps T, T, to grip the top ring of the boiler and screw down on to the cover S, the lower ends of such clamps being retained in a recess to keep them in position, but allow them to fall back when unscrewed, as shown by dotted lines T^1.

The circulation of the liquor in the boiler is provided for by having a passage through each box, open at top and bottom, and leaving an annular space all round the inside of the boiler outside the boxes, in connection with a space at top and bottom of the boiler, so that there is a constant flow of liquor down the centre of the boiler to become heated, whilst the liquor in the space all round the inside of the boiler, on becoming heated, will rise upwards and flow over the top of the top box, and down the central opening, thus causing a constant agitation, and the liquor is continually carried from the bottom upwards between the boxes and the boiler, and prevents its being burnt, and the heat is more quickly taken up by the fluid and distributed more uniformly through the boiler.

F. B. Houghton's Process.—This invention has greatly facilitated the manufacture of paper pulp from straw, wood, and other vegetable substances, by the use of steam at a higher pressure than had hitherto been employed.

An alkaline solution is used of a strength equal to from $6\frac{1}{2}°$ to $7°$ or more of Beaumé, and heated in a suitable boiler to such a temperature as to produce a pressure of from 180 lbs to 190 lbs. on the square inch; less heat and pressure may be resorted to, when using the strength of alkaline solution above mentioned, but the same must be continued during a greater length of time. The strength of the alkaline solution may also be reduced to some extent, say to $4°$ Beaumé, provided the heat and pressure is greater, or continued for a greater length of time than is required when using a solution of $7°$ Beaumé. In constructing suitable boilers for these purposes, Houghton heats the contents by means of tubes in which hot water is circulated, according to the

system invented by A. M. Perkins, as by such means the process may be carried on more safely and advantageously.

A strong cylindrical boiler is therefore used with hemispherical ends, the upper end being formed in such manner as to act as a movable cover, on which is a safety-valve; at the lower end of the boiler coils of wrought-iron tubes are introduced, suitably arranged to have highly-heated water circulated therein, by which the interior contents of the boiler can be more conveniently heated up to and retained at the high degree of temperature requisite than by any other system of heating. The matters to be treated are introduced into the interior of the boiler by means of a cylindrical basket or open metallic frame surrounded on all sides with strong wire gauze. The materials are packed into the basket in a succession of layers, supported on a series of movable partitions or circular frames of wire gauze, which are retained in position within the cylinder by pins or bolts passed through the uprights of the frame of the cylinder, and the same is lowered into the boiler, the upper end of which is then closed. The boiler is filled with the alkaline solution from a suitable cistern, and such solution may be introduced in a heated or cold state. The highly-heated water caused to circulate in the coils of tubes within the boiler will quickly raise the temperature of the contents of the boiler. A temperature varying from 376° to 380° of Fahrenheit, equal to about 175 to 185 lbs. on the square inch, and continued from ten to thirty minutes, according to the nature of the vegetable fibrous matters for the time being under process, are the best for general purposes. The time of the process varies according to the nature of the vegetable fibrous matters, and no more precise or exact rule can be given; but a workman will quickly become acquainted with the proper time for a particular description of vegetable fibrous matter; and it will only under any case be necessary from time to time to allow the apparatus and its contents to cool down, and to remove the cover, in order to ascertain whether the desired result has been obtained; but this will seldom be necessary after some practice, and principally when for the first time acting on some vegetable fibrous substance not previously treated.

An apparatus, the invention of M. H. Voelter, has come into use for the manufacture of pulp from wood. The principle involved is the grinding of pieces of wood into a pulpy condition, by forcing them against revolving grindstones; and although the pulp thus obtained is of less commercial value than that prepared by the chemical process, the machinery has been largely adopted for the manufacture of stock for such papers as do not require a very fibrous substance.

Fig. 6120 is a sectional elevation of Voelter's apparatus. The grinding surfaces consist of natural or artificial stone, and may be set horizontally or vertically, and the pulp may be introduced at either side, as desired, only in order to grind wood the stones must be well cut, and so set as scarcely to touch each other, so that the fibres may not be reduced to powder. In order that the coarse fibres contained in the pulp should not prove injurious to it, it is conducted to the sorting apparatus.

Under the rotary pulper or stone S is a vat K, in which the mixture of fibres of wood and waste are collected; an iron rake R in this vat seizes the splinters and larger refuse pieces, in order that these latter may not be driven against the frame E, which is mounted at the opposite side, and is provided with a fine sieve, which the splinters might damage. The useful fibres are washed from the rake by means of water supplied from a pipe G.

To effect the immediate assorting of the fine fibres, the curved incline D and sieve-frame E are adapted to the apparatus. Upon this sieve-frame E is stretched brass-wire gauze of the required degree of fineness. The rotary motion of the stone throws the mass of fibres contained in the vat K over the inclined plane D against the sieve-frame. The large fibres which cannot pass through run down into the refining apparatus, whilst the fine fibres, which have passed through the sieve, run direct into the pulpy mass coming from the refining apparatus in order to be there diluted.

In Voelter's first arrangement the space in which the pieces of wood to be ground into fibre are deposited was formed of plates of iron raised against the middle of the stone, so that the space became narrower towards the bottom, which frequently caused the blocking of the feed aperture by the pieces of wood, and impeded the feeding operation. This defect is remedied by substituting for the transverse plates wedge-shaped plates Q, so that the two sides of the space are parallel to each other.

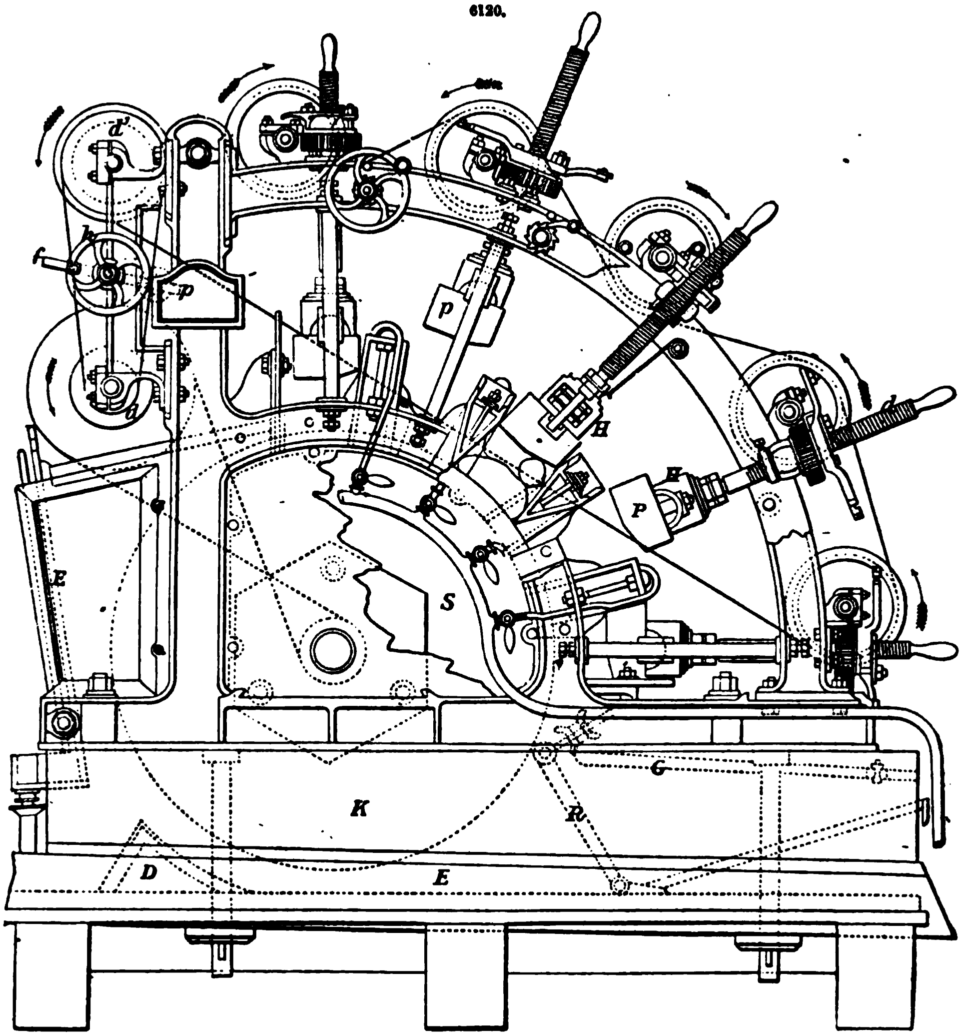
By forming the wooden pressers P as inclined planes, which rise from the middle to the front, the formation of wedges by the wood being ground is prevented. Above the wooden pressers are india-rubber buffers or steel springs, enclosed within iron sockets, the pressure of which corresponds to the normal pressure; and when this is exceeded, the rubber buffers give in a corresponding degree, so that neither the stone nor the machine is exposed to injury from any shocks or sudden strain. The iron socket H, which encloses the buffers, and which is screwed upon the pressing wood P, is provided with a cover, maintained in place by means of screws, these latter serving at the same time to regulate the pressure of the buffers. On a greater resistance taking place from below, it will act first against the pressing wood; this transmits the pressure to the buffers, which are thus more forcibly compressed, so that the socket will project above the cover, whilst the screwed rod *d* does not alter its position or action; there is therefore in the pressing wood a corresponding portion cut away for this latter.

To maintain a regular working of the grinding apparatus and to feed it conveniently, according to the surface of the wood to be operated upon, or according to the motive power, in order to be able to increase or decrease the speed with which the pressers move against the stone, a regulating apparatus is applied to the back of the machine, consisting of two cones d and d^1, and a guide-rod s, with a fork f and roller p. The cone d receives its movement directly from the main driving shaft, and communicates it to the cone d^1, the shaft of which actuates the different driving pulleys of the shafts by a band passing over and under them. According to whether the attendant turns the hand-wheel h from left to right, or *vice versâ*, the feed becomes weaker or stronger.

After leaving the pulping apparatus, the half stuff is carried through an assorting arrangement, consisting of vats provided with sieves, to which an oscillating motion is communicated by cams.

The pulp is then raised by an elevator, and passes between a pair of horizontal grindstones, which remove any remaining inequalities.

6120.



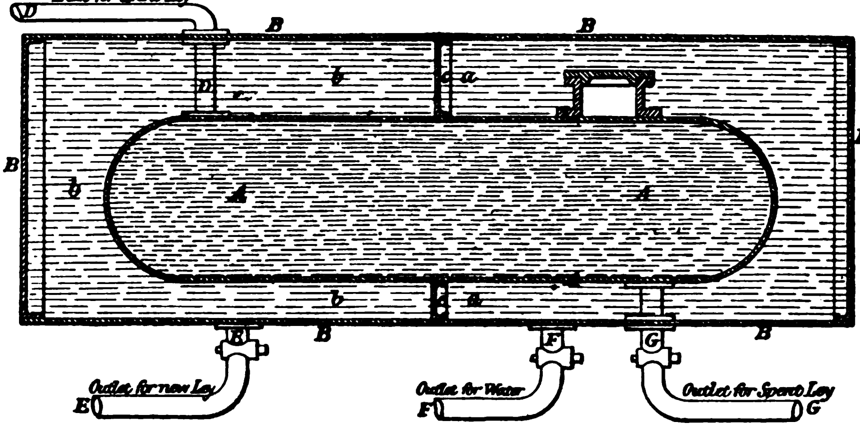
Sinclair's Evaporator.—By distilling and evaporating the spent ley resulting from the preparation of wood or other fibrous substances employed in the manufacture of paper stock, the oils, turpentine, soda-ash, or other substances contained in the ley, are recovered for useful purposes.

After the wood or other fibrous substance has been treated by boiling it in the ley, the hot ley and steam are blown into a vessel placed in a tank, having a water-tight division or partition connected both to the central part of the tank and the central part of the vessel. This tank is filled up with liquor, which may consist of new ley in one compartment of the tank, and water in the other compartment, so that the vessel contained in the tank is thus immersed in the liquor, and receives heat from the hot ley and steam blown into the vessel from the boiler. In this manner hot water is obtained for washing the pulp in the boiler, and hot liquor is provided for the next charge of the boiler, thereby saving time and fuel. The spent ley, after having thus parted with its heat, is discharged from the vessel into a distilling apparatus, when the oils and turpentine are taken off; or the spent ley may be taken direct from the vessel to the evaporator, which consists of a shaft or tower containing one or more winding flues. At the lower part of the shaft or tower two hearths or roasters are situated, having a division wall between them. One end of each hearth is connected to a furnace. Between the furnaces and hearths are two chambers; that nearest the furnace being a mixing chamber or smoke-burning chamber, whilst the other is a chamber for receiving the flame from the furnace and distributing it to the hearths or roasters. Hollows are formed in the wall between the chambers, and in those constituting the upper parts of the chamber through which the air for maintaining the combustion is supplied, and thereby becomes heated. When using the evaporator the furnaces should be fired alternately, so that when smoke is issuing

from one furnace a bright hot flame issues from the other furnace, and both enter the smoke-consuming chamber, when they mix with the required quantity of hot air for their combustion. At the top of the tower a tank is situated for holding the spent ley which is to be evaporated, with a chimney passing up through it or near to it, containing a steam jet for the purpose of producing an upward current and a partial vacuum in the winding flues of the evaporator, thus aiding the evaporation and causing the products of combustion, steam, and fumes to pass over the roasting ash and boiling ley in the hearth and flues up through the chimney and into the atmosphere. When the spent ley is ready for evaporation, it is discharged from the tank into the winding or spiral flues, down which it travels until it reaches the bottom, where it enters the roaster or hearth, and it is then stirred up and roasted by the heat from the furnaces until ready for being withdrawn.

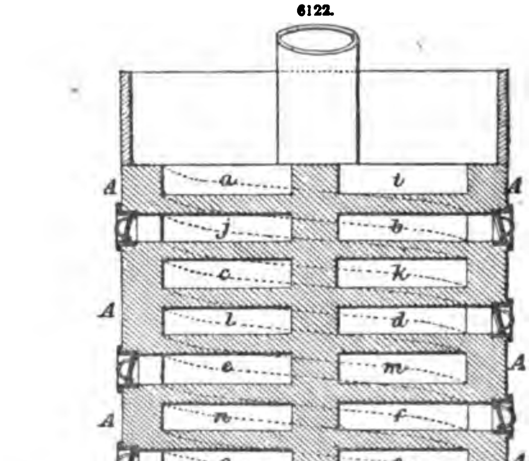
Fig. 6121 is a longitudinal vertical section of the first part of the apparatus; it consists of a

6121.



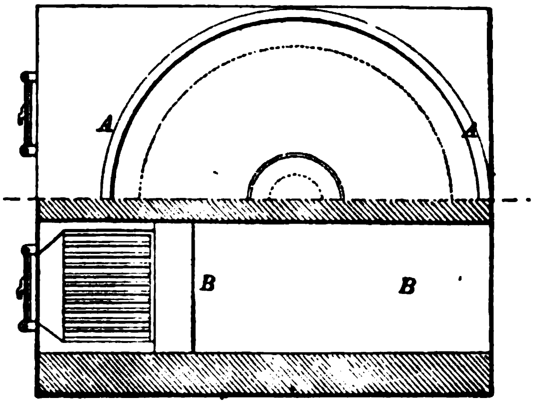
vessel A, of a cylindrical form, situated in an oblong tank B, divided into two compartments by a water-tight partition C, connected to the central parts of the tank B and of the vessel A, as shown. Both divisions of the tank B are filled with liquid, water being introduced into the compartment a, and new ley into the compartment b, so that the vessel A is entirely submerged in liquid. The vessel A communicates by a pipe D with the boiler in which the wood or other substance employed in the manufacture of paper stock is treated. After the fibrous substance has been treated in the boiler, the hot ley in which it has been boiled and the steam are blown through the pipe D, into the vessel A, where the heat given off in cooling one charge of the spent ley is utilized in heating the fresh or new ley contained in the chamber b of the tank B, previous to another charge of the said new or fresh ley being conducted through the pipe E into the boiler, where it, together with the wood or other fibrous substances, are boiled. In this manner hot ley is provided for each new charge of the boiler, thereby saving time and fuel. Previous to introducing a fresh charge of ley into the boiler, or to removing the wood or other pulp left therein after the spent ley has been drawn off into the vessel A, a stream of water from the chamber a of the tank B, which has also become heated by the cooling of the spent ley in the vessel A, is conducted through the pipe F into the boiler, in order that the pulp contained therein may be thoroughly washed before it is removed from the boiler, and also that the boiler itself may be washed out before the fresh charge of ley and of wood, or other fibrous

6122.



substance, is introduced. After such washing of the pulp and of the boiler is effected, the water is run off through a cock in the bottom of the boiler, and the pulp may then be removed. The spent ley, after having parted with its heat to the new ley contained in the chamber b, and to the water contained in the chamber a of the tank B, is discharged through the pipe G into a distilling apparatus, which may be of any ordinary type of still, wherein the ley is kept at a temperature sufficient to drive off from it the volatile matters, such as oils and turpentine, contained therein.

6123.



Section on line x. x.

Instead, however, of first distilling the spent ley, it may be conducted direct from the vessel A to the evaporating apparatus; tower or shaft may be of a square form, oval, or circular.

Fig. 6122 is a vertical section of a circular evaporator; Fig. 6123 is a part plan and part horizontal section of the same on the line x x. The flues through which the spent ley travels on its course to the hearths or roasters B are arranged spirally in the interior of the tower A, as shown by the dotted lines; the flue which commences at a winds round to b, thence to c, d, e, f, g, and terminates at h, where it discharges on to the hearth or roaster B, and the flue commencing at the upper end of the tower A in the position marked i, winds round by j, k, l, m, n, o, and p, and discharges the ley on to the other hearth or roaster B, from whence the ash, after having been sufficiently dried and roasted, is removed through side doors. When the spent ley is ready for evaporation, it is conducted to the tank on the upper end of the tower A, whence it is discharged into the winding flues, down which it travels until it reaches the bottom of the tower A, where it it discharged into the roasters or hearths B, B, and is then stirred up as required, by an attendans inserting an agitating instrument through the side openings, and roasted by the heat from the furnaces until the ash is ready to be withdrawn. The ley as it passes down through the flues is partially evaporated by the heat and waste products of combustion passing over it up through the flues on their course to the chimney. Sometimes a jet of high-pressure steam is introduced into the chimney at the lower end, which, blowing upwards, causes a partial vacuum in the flues, facilitates the draught of the furnaces and the evaporation of the ley, and also aids in drawing off the products of combustion, steam, and fumes of the roasting ash and boiling ley in the hearths and flues, to the chimney. The flues of the tower or shaft A are provided at each turn with traps or doors, that they may be easily cleaned out as required.

PARALLEL MOTION. Fr., *Parallélogramme de Watt;* Ger., *Watt'sche Parallelogramm;* Ital., *Paralellogrammo;* Span., *Movimiento paralelo.*

See Details of Engines.

PAWL. Fr., *Déclic;* Ger., *Sperrhaken;* Ital. *Nottolino;* Span., *Lingüete.*

A pawl or paul is a short movable piece or bar connected at one end by a joint with some part of a machine, while the other end falls into notches or teeth on another part in such a manner as to permit motion in one direction and prevent it in the other, as in a capstan or windlass.

PENDULUM. Fr., *Pendule;* Ger., *Pendel;* Ital., *Pendolo;* Span., *Péndulo.*

See Gunnery.

PERMANENT WAY. Fr., *Voie permanente:* Ger., *Beständige Befestigung;* Ital., *Binario permanente;* Span., *Via.*

The permanent way of a railway may be described as that portion of the line which is last constructed, which directly supports the whole weight of the rolling stock, and is, in consequence, subjected to the greatest amount of tear and wear. The term permanent is used to distinguish it from the temporary way or road, which the contractor usually lays down for his own use, during the construction of a line of railway. In the laying down of this temporary road, he must find his own rails, sleepers and fastenings, as he is not permitted to use those belonging to the company, which are intended to carry the traffic of the completed line. When his own road has answered its purpose, he proceeds to remove it, and lay down that of the company, and hence the application of the term permanent way in contradistinction to that of temporary.

The permanent way consists of rails, sleepers, chairs, transoms, ties, bolts, spikes, and such other minor accessories as may be necessary to connect the several component parts, and ensure the stability and rigidity of the whole road.

Generally speaking, all descriptions of permanent way may be classed under one of two heads. Those in which the rails are supported by sleepers continuous throughout their entire length, and those in which the sleepers are placed at intervals along the same length. Briefly, these may be termed the longitudinal and the transverse permanent way. In some isolated instances sleepers have been dispensed with, and the rails laid upon the naked ballast, but this method, which will be noticed in its proper place, has had a very limited application in practice. Under the second general classification of permanent ways, are included all those in which, although the sleepers cannot be correctly called transverse sleepers, yet they certainly do not come under the category of longitudinal ones. Of this type are the many varieties in which the rails rest upon

iron sleepers, which do not extend across the road or track, but, while spaced at regular intervals, each one is connected with its opposite fellow by a transom or tie-rod. To this description belong the different iron roads, as well as some of a very primitive class, in which the sleepers consisted simply of large roughly-squared blocks of stone.

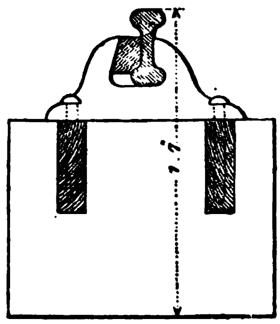
Before proceeding to describe the principal systems of permanent way adopted on our leading railways, as well as on those on the Continent, and elsewhere abroad, it will be advisable to direct attention to the essential component parts of the road, and the particular functions which they have to perform. Evidently while we have classified all the various descriptions of roads under two general heads, there are numerous subdivisions so far as the component parts are concerned. Some roads dispense with chairs, others with sleepers, and the modifications which the joints and fastenings undergo, are well-nigh infinite.

The permanent way is always laid in good ballast whenever it can be procured, and when it is not to be obtained, the best substitute is employed that is available. For further information on the subject of ballast, and the laying of the permanent way, the reader is referred to 'Ballast' and 'Railway Engineering' In addition to the actual component parts of the permanent way, there are several details which inseparably belong to it, which will be described in the present article. Of this character are points, crossings, junctions, and switches On many of our main lines, the points are connected with the signals in such a manner that they cannot act independently of one another. These will be found more particularly mentioned under the head of 'Signals.' Under its own title, will also be found 'Turn-tables,' which, if not strictly belonging to the present subject, is very closely connected with it It will be seen as we proceed, that with the exception of the total abandonment of the stone sleeper or block, very little radical change has been effected, although numerous modifications have been introduced in the permanent ways of railroads Thus, iron sleepers are employed in countries in which the ravages of the white ant preclude the use of the ordinary timber, which is there procurable, whether chemically preserved or otherwise. Rails are every year becoming heavier and heavier, and steel is on several important lines fast superseding its predecessor, rolled iron, in order to afford a sufficient degree of resistance and durability, to the ever-increasing requirements of the massive locomotives which are now built.

There are several qualifications indispensable to every system of permanent way. Each system must be fixed so securely that the gauge cannot alter. It must maintain a horizontal position in the plane of its cross-section, except in the case of curves. There must be no unevenness in a longitudinal direction, or the progress of the train would be attended by a constant succession of jumps and blows, which would seriously augment the friction and prove very detrimental to the axles and springs. The friction between the wheels and the rails should not be more than what is sufficient to afford the necessary amount of tractive adhesion. So far as the rails are concerned, they must be strong enough between the bearings, or points of support, to carry the heaviest load which can come upon them, without undergoing any deflection of importance. In every permanent way, there must be a certain amount of elasticity, so as to absorb or render inoperative the impact between the wheels and the rails. Without this essential feature, the rolling stock soon gets knocked to pieces. The road, considered as a whole, must be so constructed as to admit of being easily repaired at any part, readily packed, removed, replaced, and well drained. Every system or description of permanent way, and their number is infinite, fulfils several of these conditions more or less perfectly, although it would be perhaps too much to assert that any one fulfils them all thoroughly. Besides, some systems are not so well adapted to certain circumstances as others. For example, in countries in which the white ant is found, it is preferable to use iron instead of timber sleepers, owing to the ravages committed by those insects on wood of every kind. It is, however, stated as a fact, that white ants rarely attack timber sleepers, over which trains are constantly running. It appears that the vibration destroys them, before they can effectually establish themselves in the wood.

While numerous minor modifications have been introduced from time to time in the permanent way of railways, without much apparent reason, it will be found that those which are deserving of attention, have been the result of considerable experience and knowledge of the especial characteristics which constitute a really good, sound, and serviceable road. A little consideration of the nature of the original type of permanent way, and of the reason for its being abandoned, will enable the reader to form an accurate idea of the chief points which must be attended to, in order that a permanent way may adequately fulfil the duty demanded of it. This primitive type, shown in cross-section in Fig. 6124, consisted of stone blocks about 2 ft. × 2 ft. × 1 ft. in depth. The rails were laid in cast-iron chairs. The description of stone used depended upon the locality. The blocks were laid sometimes square to the road, with spaces intervening, and at others, diagonally, with the corners almost in contact. They were in most instances bedded in ballast, but frequently rested on the formation level without either ballasting or boxing.

6124.



In this original system of permanent way, the ruling principle was solidity, and it was never considered at the time that a road might be a great deal too solid. With this object in view, the chairs, which were of cast iron, were very accurately fixed in the stone blocks, and fastened to them by a couple of spikes. The latter were driven into oak treenails, which were inserted in holes in the blocks, having a depth of about 6 in. It is to be noticed here, that there was no elastic medium of any kind between the chair bed and the stone sleeper. Consequently, after a short time, the chairs became loose and cut into the blocks, which con-

tingency was expected to be obviated by introducing a layer of felt between the chair and the block. This attempt proved a failure, and the evil was, if anything, increased.

In order to test the value of a perfectly rigid unyielding road, and to determine whether it was adapted for the purpose of a permanent way, a very crucial experiment was carried out on part of the Leeds and Manchester Railway. A portion of the solid rock, the nature of which precluded the idea of any subsidence or yielding taking place, was levelled, and the cast-iron chairs were fastened to it, in exactly the same manner in which they had been laid on the stone blocks. The result was a road so hard and unyielding, that it was idle to think of running over it, as, independently of other considerations, it was ruinous to the rolling stock. Moreover, the discomfort to the passengers from the continual noise was unendurable. This unsuitability of a perfectly rigid road was also demonstrated by another experiment, in which the chairs were laid on continuous walls of masonry. These experiments proved that some elasticity in a permanent way was absolutely necessary to the proper fulfilment of its duty, and their result was the general abandonment of the stone blocks, and the substitution of timber for stone. It has been well pointed out, that instead of dispensing altogether with the stone blocks, they might have been advantageously employed as a foundation for the timber sleepers, and had they been placed as suggested by W. B. Adams, in rows so as to form a continuous support, a very good road would have resulted. The noise which was occasioned when the chairs were placed on the stone sleeper, was due to the deflection of the rail, and the rising and falling of it on the chairs upon the blocks. It must not be supposed, because there is no noise of this description on the timber-sleeper roads, that there is no deflection of the rails. The contrary is proved by the slush which exudes from underneath the sleepers in wet weather, and by the whirlwind of dust which in dry weather marks the progress of an extra fast train. The necessity for packing sleepers is also a corroborative proof.

Timber selected for sleepers should be sound and well seasoned. In many instances inferior descriptions are selected, and dependence is placed upon the chemical solution with which they are impregnated, for increasing their durability and powers of resistance. The light and cheaper kinds of timber absorb more readily chemical preserving solutions than the better and firmer sorts, and are to a certain extent benefited by the preservative process. Of all woods oak is the best, but the expense debars it from being used. Experiments have proved that spikes hold with twice the force in oak than in other woods. The dimensions of sleepers, the distance at which they are placed apart, and their form, vary with the description of permanent way adopted, the different varieties of which will be illustrated in the present article. The chief object of a sleeper is to give a firm bearing upon the ballast or road proper, and at the same time to afford a sufficient base or bed for the rail. The tendency of the rolling load upon the sleepers, is to force them all down and cause them to sink into the roadway, and to prevent this, a considerable amount of bearing surface upon the road is necessary. Sleepers occasionally act as ties, but their use in this manner is objectionable, and tends to encourage the idea that their proper duty is to keep the gauge of the line, which is not the case. Tie-rods should always be used to discharge this duty belonging to the permanent way. If the dimensions of the sleepers are unequal, those which are smallest will yield first under the rolling load, and thus the whole road will get out of level. When stone sleepers were used, which made a most uncomfortably rigid road, and were consequently totally abandoned, those which happened to break were sometimes replaced by wooden ones, but the road at once became dangerously uneven, and the difference in their power of resistance was so great that it was found impossible to employ them together. If sleepers all of the same material, but of different dimensions, must be used, those which are smallest should be spaced closer together than the larger ones. On the whole, it would be better to use sleepers all of one dimension, even if they were small, than some of small and others of larger size.

There can be no really good permanent way without ample bearing surface being provided for the sleepers. In France, the experiment was tried of sawing the sleepers in two at the middle, and leaving one whole one, here and there, to bind the whole road together. The object of this was to nullify the spring of the ends of the sleepers, which deflect at those points under the passing load, and disturb the ballast and boxing in a manner which very much deteriorates the road. It was with the same object in view that Brunel had a part of the permanent way on the Great Western line piled, but the plan was soon abandoned. In Austria, where the timber is valuable, wooden sleepers are sometimes planed, which not only improves the bearing surface, but prevents decay. The operation may be an improvement, but one which would scarcely pay in a country where labour is as dear as it is here. Where the single-flanged, or contractor's rail, as it is termed, has been laid, the sleepers are sometimes grooved by machinery to form a bed for the rail. This helps to keep the road in gauge, but, on the other hand, it weakens the sleeper, and facilitates the lodgment of water, which accelerates the decay of the timber. Probably, the principal cause of the deterioration of wooden sleepers is the crushing of the wood under the rails, that is, in the rail bed. An insufficient description of fastening, want of proper bearing surface on the rail bed, and want of adequate bearing of the sleeper upon the ballast, are the chief reasons for this deterioration. It is a common circumstance to witness, on a poorly-ballasted line, or where the width of the sleeper is too small, the sleepers quite loose, or only held together by their fastenings with the rail. Directly a train passes, the loose sleeper is violently driven down as if by a blow. No amount of chemical preservation will prolong the life of a sleeper which is subjected to treatment of this kind.

Much has been said with respect to the relative merits of the transverse and longitudinal sleeper roads, but the former, with a few exceptions, is that generally adopted. The advantage of the latter is, that it certainly gives an easier road to run on, and favours the life of the rolling stock, but it is a more expensive one to maintain. It, moreover, is not so easily drained as its rival. This latter is a serious disadvantage, as efficient drainage is one of the essential characteristics of a good permanent way.

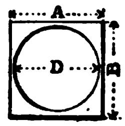
6125.

6126.

6127.

6128.

6129.



Bearing Surface of Sleepers.—The ordinary sections of timber sleepers are shown in Figs. 6125 to 6128. When rectangular in shape, and placed transversely, their usual dimensions are, for the standard gauge, about 9 ft. long × 10 in. wide, × 5 in. deep. Originally they were 7 ft. × 4 in. in section, and laid 5 ft. apart, but they are now placed at distances of 3 ft. apart, and are often 12 in. × 6 in. cross-section, and there is an additional sleeper at each joint in general practice. The triangular sleepers in Fig. 6128 were first used on the South-Eastern Railway thirty years ago. They were formed by a square balk being diagonally divided, so as to cut out four triangular sleepers, which were laid with the apex downwards. These have as much bearing surface as sleepers of twice the cubic content, cut out as a half balk in the usual manner.

In the longitudinal system the bearing of the sleeper on the ballast is not less than 12 in., and the depth 6 in., but on the Great Western and some other lines upon which it is used, these dimensions are increased to 14 in. and 7 in. respectively. The quantity of timber used in the transverse system, with four intermediate sleepers to each length of rail, is not quite 16 cub. ft., while in the longitudinal it is rather more. With nearly the same quantity of timber, the bearing surface on the transverse system will be about 12 in., and in the other about 1 in. more. But in the latter, as the depth of the sleeper is 1 in. over the whole surface, the additional quantity of timber is nearly 3 cub. ft. Since the quantity of timber is nearly the same, and as the cost of the rail fastenings may be considered equal, the total cost of the two systems should be the same. One reason why the transverse system was for a long time regarded as the cheaper, was because on many lines the sleepers were inferior both in size and quality to those used on the longitudinal road. The latter requires timber of larger scantlings and better quality than the former.

The longitudinal system, although continuous, by no means prevents deflection of the rails. On the old Croydon line, where that system was used, the rails were frequently found broken, and were repaired by a plate fixed under the broken ends. It should be mentioned, however, that the rails, which were of the bridge form, were very light in section. So far as the cost of repairs of the two systems is concerned, that of the longitudinal will be the heavier. The packing will be less than in the transverse, but the timber is more crushed than in the other system, in which chairs are used, and it is more troublesome to get at the bolts and fastenings. It cannot be denied, and the examples we shall adduce of the systems of permanent way in most general use on the present lines, both at home and abroad, will corroborate the statement, that rails fixed in cast-iron chairs by wooden keys, and laid upon transverse sleepers, constitute the modern type of road mostly in favour with engineers. Exceptions exist, but they are few and far between, and are, moreover, due to some especial local features which necessitate a departure from the general rule.

A great deal has been said against the employment of timber sleepers in India, and in consequence of the difficulty in procuring, or preserving them, those of iron have been extensively used there. From experiments carried out on the Madras Railway with timber sleepers, it was found that out of sixteen different woods, five only were in a sound condition at the end of a couple of years. Of the others, those sleepers which had been uncovered, were less decayed than those which had been completely embedded in the ballast, and the decay was invariably noticed to commence under one or both chairs. This was, no doubt, owing to the retention of moisture there, and might be prevented by giving a good coating of tar to the chair beds. The sleepers which failed on the Madras line may be divided into two classes. The first comprises those which were originally of perishable woods, and consequently unfit for the purpose, and the second those which, although of a good quality of timber, had been cut from young trees, and had not been sufficiently matured. Of the whole amount of timber in India available for conversion into sleepers, about 62 per cent. could not be used in the natural state, and were practically useless, because no artificial means existed in the country for preserving those kinds of a perishable character.

In every specification attached to a contract for the delivery of sleepers, beams, balks, or other timber intended for engineering or architectural purposes, one of the most important clauses is that which specifies the amount of heartwood which the balk or beam must possess, in order to ensure its being passed by the engineer or other person deputed to examine it. It is calculated that a certain quantity of perfectly sound and well-seasoned timber ought to be obtained out of every balk, and this would not be the case, should the timber contain more than the allowable proportion of sapwood. It is a matter, then, of some importance and of considerable convenience to the person, in whose hands rests the responsibility of passing or rejecting timber, to be able to ascertain speedily and accurately, whether the blocks under his examination possess a sufficient amount of heartwood to furnish good and sound material for the purposes for which they are intended. A short rule by Thomas Cargill will enable anyone to calculate a table by which he can discover, by simple inspection, whether a piece of timber will give or not, the quantity of heartwood required by the specification. In any balk of timber, the heartwood is found disposed in a pretty uniformly circular figure around an imaginary line passing through the centre of the balk, and may be regarded as its longitudinal axis. This is shown in Fig. 6129, which is a section of a balk of timber, and in which the inscribed circle shows the heartwood, and the rest of the figure exterior to the circle represents the amount of sapwood which the balk contains. It may be mentioned that the sapwood is that portion of the timber which is of the newest or more recent growth, which, owing to the premature felling of the tree, has not had time to acquire the consistency and close-grained structure of the interior parts. The sapwood, which is unfit for constructive purposes, would become heartwood, if the tree remained unfelled; and were the tree permitted to attain to maturity, there would be scarcely any sapwood whatever.

In Fig. 6129 let A and B be the breadth and depth respectively of the balk, D the diameter of the

circular portion of heartwood, and let N represent the proportion of sapwood allowed in the specification. The total amount of heartwood will equal the difference between the contents of the whole cross-section of the balk and the proportion of sapwood. Calling this H, we have $H = A \times B - N \times A \times B = A\,B\,(I - N)$ Again, as the heartwood lies wholly within the circular portion of the figure, the area of this circle must $= A \times B\,(I - N)$, which gives the following equation; $\frac{\pi D^2}{4} = A \times B\,(I - N)$, in which π is the ratio of the circle to its diameter. Solving for D, we obtain $D = 2\sqrt{A\,B} \times \sqrt{\frac{I - N}{\pi}}$. As the length of the piece of timber is common to both sides of the equation, it would be superfluous to introduce it. In cases of square balks in which $A = B$ the equation becomes $D = 2\,A\sqrt{\frac{I - N}{\pi}}$.

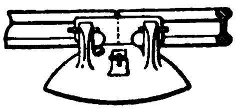
As A, B, and N are always known, it is easy to construct a table for the corresponding values of D, and all that remains for the inspector of the timber to do, is to lay his rule across the centre of the balk, and ascertain whether the actual and calculated length of D coincide. Since N, in the same contract, is generally constant, the calculation is very much simplified, particularly in the case of square balks which are the most usual. The value of $\sqrt{\frac{I - N}{\pi}}$, once determined, suffices for all the different values of A and B The quantity of sapwood, which was sometimes permitted to remain in sleepers, very speedily led to their decay, especially in the case of transverse sleepers.

It was the great inferiority of the timber used in cross sleepers, which suggested to Reynolds the idea of a composite sleeper. He proposed to use one composed of cast iron and wood.

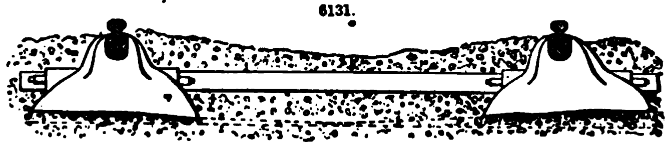
The shape of the sleeper was that of an inverted trough, whence it obtained the name of the hog-trough sleeper: the body of the trough being of cast iron and the lining of timber. The idea, however, did not fulfil the expectations of the inventor, and it was not until ten years subsequently, that a metal sleeper was introduced which has done good service to the road.

Cast-iron Sleepers—It was not long after the introduction of iron, under a variety of conditions, to the requirements of railways that it was attempted to employ it as a substitute for sleepers. The first cast-iron sleeper which has been used with success on existing lines was that of Greaves, which possesses several very commendable features. It is shown in front elevation in Fig 6130, and in side elevation in Fig. 6131, which latter view constitutes a cross-section of the permanent way used in

6130.

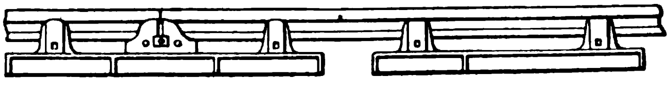


6131.

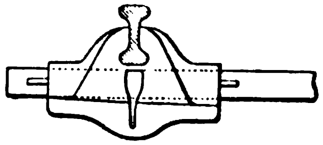


Egypt, India, and other countries in which the sleeper has been introduced. The sleeper consists of a cast-iron bowl with the chair cast on it, which may be of any section to suit the rail. Each sleeper is connected with its opposite neighbour by a transverse tie-bar, see Fig. 6131, which keeps the gauge in order. In Fig. 6130 the joint-chair is shown, which is a double-headed chair, with loose fishing plates of either cast or wrought iron attached to the rails by split iron keys. The merits of this system are that the sleeper is strong in form, has a good hold of the ground, and is not liable to be detached from the chair, which forms part and parcel of the same casting. Moreover, the load is brought directly over the whole bearing surface, and the ballast is always maintained in a dry and elastic condition. The opposite sleepers cannot separate laterally, owing to the transverse tie-bar forming part of the system. The packing, which is a serious difficulty to many metal sleepers, is accomplished in a very ingenious manner, by means of a pointed rammer, through a couple of holes provided for the purpose. In this manner the sleeper and rail can either be raised without disturbing the ballast, or lowered by taking some of it out. All opening of the ground is thus prevented, which in wet localities is a very great advantage. It was found on the Egyptian railway, that these packing holes gave some trouble, as the soft soil upon which the sleepers were laid was forced up through them. Measures have since been taken to obviate this inconvenience.

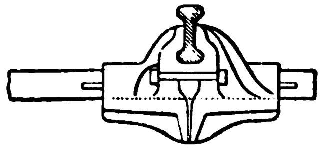
6132.



6133.



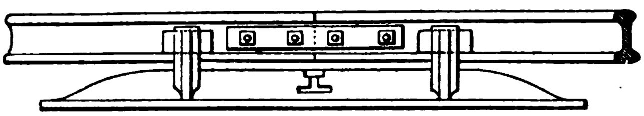
6134.



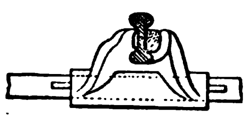
In Figs. 6132 to 6134 are represented in front elevation, in end elevation, and in cross-section, the cast-iron sleeper introduced by P. W. Barlow. Each sleeper is in two separate pieces,

united by a wrought-iron tie-bar, and is composed of a plate 3 ft. long × 7 in. in width, with two half chair heads cast upon it. The joint-sleeper in Fig. 6132 has three half chair heads cast on it, which grip tightly the lower half of the rail, by means of screw-bolts passing through the chair heads below the rails. Some nice workmanship is required to make the chairs and the rails fit closely, a condition very unfavourable to their employment. Another cast-iron sleeper was invented by W. H. Barlow, somewhat similar to the former. It is cast in one piece, as shown in Figs. 6135, 6136. The rails are fixed to the chairs by the ordinary keys. These sleepers were used for a time on parts of the Midland Railway. The cast-iron sleeper which appears to possess the most advantages, although not the most extensively used, is that introduced by Samuel, and is shown in Figs. 6137 to 6139. It consists of a wedge-shaped trough, of depth sufficient to take the whole height of the rail, and has two sloping arms at the upper part to take a bearing on the ballast. In the cross-section in Fig. 6139 the manner of fixing the rail is shown. It is wedged in between two pieces of timber, which grip it at the sides and lower flange, and are in consequence themselves strongly compressed. But as these trough sleepers are not continuous, as shown in Fig. 6137, the rail must be strong enough to act as a girder, and not deflect under the passing load. The advantages of these sleepers are that they are sufficiently deep to prevent any tendency to spread, and also from the same cause get a firm hold of the ballast. One of the chief points in a permanent way is secured by the use of the wooden wedges, that is, the presence of an elastic medium between the rail and the sleeper. Moreover, as the bottom of the rail is not in contact with any iron surface, it remains uninjured, and the wooden wedges enable that nicety of adjustment and fitting, necessary in the Barlow sleeper, to be dispensed with, since they effect their adjustment through their own compressibility. Besides, the same sleeper can be used with rails of different sections, since all that is necessary is to slightly alter the shape of the wooden wedges or keys so as to fit close to the rail.

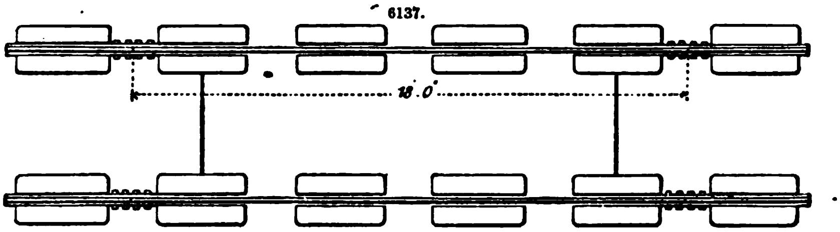
6135.



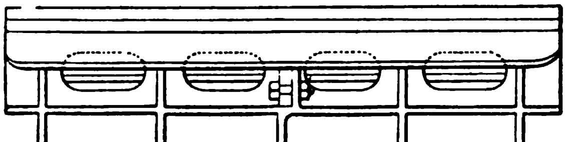
6136.



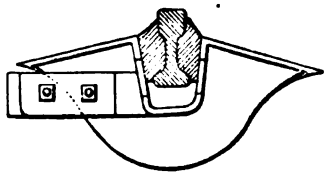
6137.



6138.



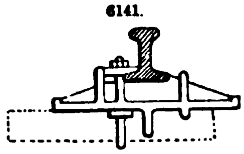
6139.



De Bergue was early in the field with cast-iron sleepers, and introduced a description of permanent way, represented in Figs. 6140, 6141. A single-headed rail is laid on a series of cast-iron sleepers, formed of a flat table, with a longitudinal rib below. To strengthen the table, a series of thin ribs, similar to a network, are cast on the upper side. A lug is also cast, to take one edge of the rail, and a loose slip of a wedge-form, with a bolt, is made to take the other side. The bolt has an eye to take the cross-tie bar below, which is lap-notched into the longitudinal rib of the sleeper. The whole arrangement is exceedingly ingenious, and possesses a considerable amount of strength, with comparatively little metal; but in a mechanical point of view, it is disadvantageous, since the rail is a prop on the sleeper. The joints are fished, and the sleepers, although longitudinal, are not continuous. The single-headed or foot rail has less vertical strength than the double-headed; and the sleepers, in order to ensure the maximum of strength, should be continuous and abut against one another. This system has been tried on the Great Northern, the South-Western, and other lines. The notch in the lower rib of the casting having been found to be disadvantageous, an alteration was made in a sample subsequently laid on the South-Western Railway. De Bergue divided the lower rib into two parts, and compensated for it by applying an upper rib. This gave a much better disposition of the material, as it placed the cast-iron rib in compression instead of in tension. It has been stated that this road costs less for

6140.

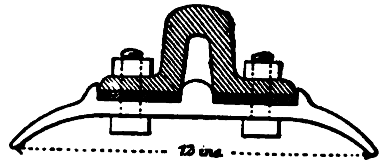
6141.



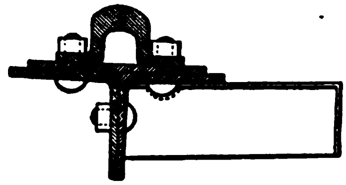
maintenance than the ordinary way. The area of surface of De Bergue's permanent way, bearing on the ballast, is equivalent to a continuous longitudinal way, having a width of 9 in. under each rail. The castings are of rather a complicated character, and there is a good deal of nice fitting to be done.

Wrought-iron Sleepers.—A longitudinal road of wrought-iron sleepers was introduced by Macdonnel, and tried on one or two lines. It is represented in Fig. 6142. The sleeper or bearing is curved downwards for the purpose of affording vertical strength. There are three ribs or projections rolled on it, one at the centre, and the other at the sides. Between the centre rib and each of the side ones the flanges of the rail, which is of the bridge section, are placed. They rest upon strips of timber, and the flanges, timber and sleeper, are all held together by vertical bolts. The form of the sleeper is strong, well adapted to prevent lateral spreading, and also to get a good hold of the ballast.

6142.



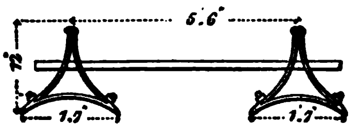
6143.



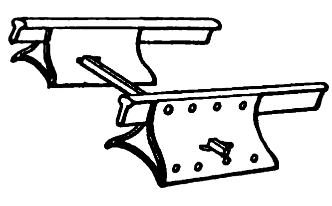
It was owing to the failure of some of the cast-iron sleepers tried on the East Indian Railway, which suggested the trial of the wrought-iron system shown in cross-section in Fig. 6143. It consists of a longitudinal sleeper, or continuous bearing, formed by two angle-irons, 5½ in. × 5½ in. × 20 ft. in length, bolted together and breaking joint every 10 ft. Upon this is placed a packing piece of hard wood, ½ in. in thickness, and through it and the sleeper is bolted a rail of the bridge section weighing 70 lbs. to the yard. The cross-ties or transoms are also of angle-iron, placed at intervals of 10 ft., and bevelled at the ends to give the necessary tilt to the rail. This sleeper possesses great strength and stiffness, and constitutes in reality a beam 9 in. in depth and 11 in. in breadth. As the central web is 5½ in. deep, it gets so good a grip of the ballast as to maintain the gauge, even on curves. It can also be packed with great facility, as it dispenses with the usual opening up of the road, and a less depth of ballast is necessary, since the bearing surface is only 3 in. below the rails.

In Figs. 6144, 6145, are shown an elevation and cross-section of Addis's wrought-iron sleepers.

6144.



6145.



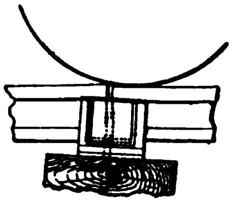
An ordinary single-headed rail is supported on the sleepers, which are formed of plates of iron or steel, rolled to the required shape, so that when brought together and fixed by bolts and nuts, or by other suitable means, they assume the form in section of a triangle, the sides of which are hollow or concave; see Figs. 6144, 6145. The rail is held by the jaws formed at the upper angles of the sleepers, and is secured by the bolts passing through the jaws and its own web. The sleepers are 3 ft. in length, fixed at distances of 6 ft. from centre to centre, which allow three sleepers to each rail, 18 ft. long, and also permits the rails to be fished in the centre of a sleeper. The sleepers are kept in line by tie-rods or bars passing through holes formed in the plates of the sleepers, and fastened to them by jibs and keys. Speaking generally of both cast and wrought iron sleepers, it may be stated that the practice of placing flat, or nearly flat, iron plates on the surface of the ballast, will be found not to answer, if from no other reason but in consequence of the injurious effects arising from frost, heavy rains, and floods. Greaves' cast-iron sleepers will not answer for high speeds, although his road is probably the best of that description, and under certain circumstances may not be much inferior to one of timber.

Chairs, Keys, and Fastenings.—In the several examples, which will be described and illustrated in this article, of the best known and most extensively employed systems of permanent way, the keys and fastenings will in many of them constitute a concomitant feature. But there are some descriptions of these indispensable adjuncts to the road, which deserve a separate notice, more especially as the changes which have been from time to time introduced, point out that improvements have been effected in them, as well as in the more prominent parts of the permanent way. The extensive use of wooden keys is due to several important advantages which they unquestionably possess. They are simple and economical; they are especially adapted for the double-headed rail; they are readily procured, and they hold the rail both laterally and vertically in the chair. The principal reason which has led to their adoption is, the elasticity of the material, which allows it to resume its original dimensions, after being subjected to a heavy compressed force. The advantages of wooden keys will probably always outweigh their disadvantages; which are, that they shrink and become loose in dry weather, and decay after tolerably short service. Oaken keys are generally unfit for further use after a period of eight years. Those which are placed at the joints last only five years, because they are exposed to a greater amount of wear and tear. They have, owing

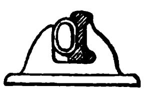
to the rail not being continuous at those points, heavier duty to do, and are more liable to work loose. Until the sleepers near the joints were placed closer together, the joint-sleepers became more depressed than those adjacent, which also injuriously affected the joint-keys.

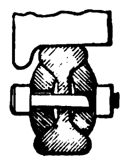
One of the results arising from the joint-key becoming loosened, is to give a cant to the chair, which throws the ends of the rails out of level, as shown in Fig. 6146. It has been proved that the chair is always canted in the direction of the line, and the joints have sometimes become so uneven that the last inch of one end of each rail is rusted, thus showing that the wheels of the carriages never touched them. If a joint-sleeper gets out of level, and the key is not securely fixed, the wheel of the advancing engine or carriage depresses the end of one rail, as in Fig. 6146, without depressing the other, and the consequence is that the wheel strikes the projecting end of the rail with a more or less violent blow. In badly-laid joints this incessant concussion is very disagreeable to the passengers of a train, and causes the unevenness of the road to be very severely felt. Some years ago Barlow introduced a hollow wrought-iron key, having a shape very similar to the wooden key, and possessing a considerable degree of elasticity, in virtue of its hollowness. This key is represented in Fig. 6147, and the stiffness, which is dependent upon the thickness of the metal, is regulated by the strength of the chair. The key is made so as to fit the rail as closely as possible, and the pressure resulting from driving it in, elongates it in a manner which conduces still further to the ensuring of a tight fit. These keys were tried on a few of the earlier constructed ines, but have failed to come into use. The objections to them are that they are more expensive than the ordinary compressed oak keys, and also require very accurate fitting, a fatal objection to keys. It should be noticed, that the compressed oak keys were originally 8 or 9 in. long, but subsequently reduced to about 4 or 5 in. An objection to the solid taper iron keys, which were employed on some lines, is that, in driving, the lower flanges of the rails are liable to be torn off.

6146.

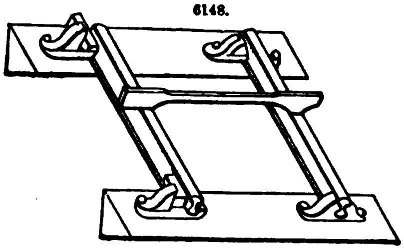


6147.



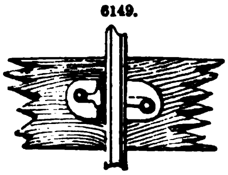


6148.

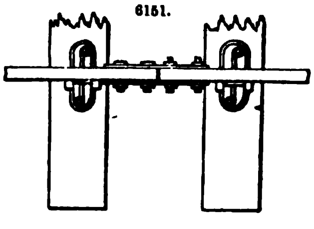


6153.

6149.



6151.



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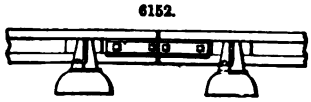

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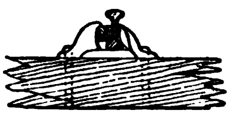
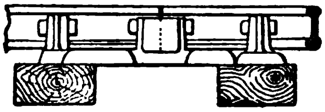


It cannot be said that a really good serviceable mode of fastening rails in the chairs was introduced, until the improved cast-iron chairs of Ransomes and May came into use, together with their compressed oaken treenails, to attach them to the sleepers. These treenails are most extensively used, and have been successfully applied to the Indian railways. In order to secure a thoroughly good fit, and give the proper cant to the rail, the chairs are cast in iron moulds, which imparts great accuracy of form. The chairs, and the mode of fastening the rails to them and the sleepers, also are fully shown in Figs. 6148 to 6150. Bridges Adams proposes as an improvement upon the shape of the treenails, that they should be made square or oblong, in order to facilitate the operation of boring the holes, and to prevent splitting the sleepers, which happens sometimes with the round treenails when the holes are not very accurately bored. A treenail of an oblong section would drive very forcibly in the direction of the grain of the wood, and would offer a greater resistance against the lurching of the engine; and it could not split the sleeper, as it would be of less width than the hole across the grain. The weakest part of the permanent way is the joints. The simplest method of strengthening them would appear to be to put an extra sleeper underneath, but as the sleepers themselves only bear on loose ballast, they furnish no continuous support. The next remedy is to take the ends of the rails altogether out of the chair, and to place a sleeper with a chair on it on each side of the joint, and thus suspend the joint between the two chairs. The rails and chairs would be connected by fishing, that is, by adding two pieces of iron, one on each side of the rail, between it and the chairs. But, in order to place the fishes or pieces of iron in the chairs, especial castings are needed; to obviate which, the simple plan was adopted of punching holes in the ends of the rails, and connecting the fish-plates together by four bolts passing through and through. The holes in the rails are made rather larger than those in

the fish-plates to allow of expansion. The first fish-plates were made of cast iron, but they have been advantageously superseded by others of wrought iron. This arrangement proved so successful, that old rails which had become useless from being worn at the ends, so that one end projected nearly a quarter of an inch above the other, worked to a level surface, under the rolling action of the trains, when firmly secured by the fish-plates.

The manner in which the fish-plates are attached to ordinary rails is shown in plan, elevation, and section in Figs. 6151 to 6153, and the whole arrangement is both simple and effectual. A proposition was made by Gordon to halve the ends of the rails into one another, by cutting off a piece from the top of one and from the bottom of the other, so that one should overlap the other. The expectation was that, by making the overlap in the direction of the traffic, the ends of both rails would be kept down together. The plan failed in practice, and was consequently abandoned. It may be mentioned here that on the Blackwall Railway, when it was worked by rope traction, the rail ends were connected together by a scarf-joint about 6 in. in length, with the points dovetailed and the whole wedged into the chair. If fish-plates are made too weak for their work, they will take a permanent set under the heavy strain they are subjected to. For this reason some engineers prefer cast-iron fish-plates, since, if they are not strong enough, they break at once, and stronger ones can be substituted, whereas when the fish-plates are of wrought iron the set is not readily perceived.

6154.



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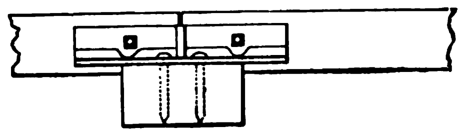
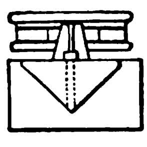
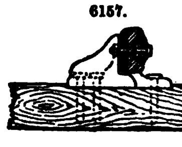


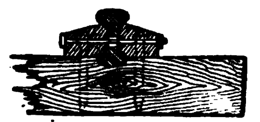
6155.



6157.



6161.



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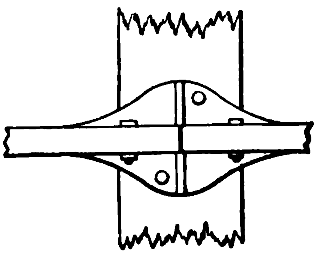
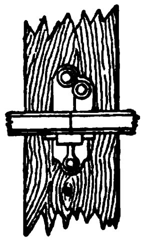
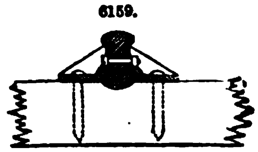




6156.

6159.



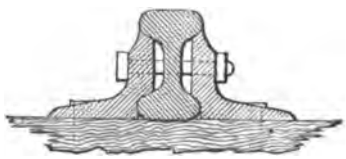
Among the many joint-chairs which have been invented, the one shown in Fig. 6154 is that introduced by John Fowler. It consists of three pairs of jaws cast in one piece on a sole-plate. The two extreme jaws rest over two sleepers, so that the joint rests suspended in the middle jaw. A neat chair invented by Samuel is represented in Figs. 6155 to 6157. It was intended to obviate the objection against the use of fish-plates, because they required an additional sleeper and chair, on lines, the funds of which were in an unsatisfactory condition. The chair in Fig. 6157 has only one jaw which fits against one side of the rail, and a wrought-iron fish-plate being placed on the other side, the whole is bolted together. While only one sleeper is thus needed at the joint, the arrangement is open to the objections which have been raised against joints being placed directly upon sleepers, instead of being suspended between them. B. Adams also proposed a plan, by the adoption of which the existing joint-sleepers on lines may remain, and the inefficient joint-chair may be replaced by the cast-iron bracket-joint, shown in plan, cross-section, and side elevation in Figs. 6158 to 6160, which has no wood keys. A pair of cast-iron brackets are bolted to the rails in the side channels by two bolts instead of four, as in the case of the fish-joint. Each bracket has a broad foot which rests on the sleeper, and is secured to it by spikes. The lower flange of the rail projects below the feet, and being grooved into the sleeper, keeps the gauge without bringing strain on the spikes, and renders the bolts a sufficiently firm fastening in themselves.

Another method of fixing rails to sleepers is that represented in Fig. 6161, also due to the same authority. Its object is to dispense with the use altogether of the cast-iron chair, and bed the rail in the sleeper with wooden wedges or brackets on each side of the rail. The lower flange of the rail is sunk 1 in. into the sleeper, and the total height of the rail above the sleeper is only 4 in. instead of 7, which is the case when the cast-iron chairs are employed. The lowering the centre of gravity in this manner is a decided advantage, and the rails could be reversed or turned to much greater advantage by the use of the wooden brackets. Referring to Fig. 6161, the two pieces of timber or side brackets are 9 in. long × 3½ in. wide × 3½ in. thick, and are bolted by a single bolt through the rail, one in each channel, the lower flange of the rail resting on a cross channel of the transverse sleeper. Spikes are driven through the pieces of oak into the sleeper to make the whole joint secure. At the joints, plates of iron are placed in the rail channels, between

the side brackets and the rail, and are secured by the same bolts. Whatever may be the assumed advantages of this particular joint, it is clear that the strength of the side brackets, which are small enough, is very much impaired by the bolts and spikes driven through them.

At one time, there was considerable difference of opinion with respect to the relative merits of a suspended fish-plate joint, and one in which the fishing was effected directly over a bearing, but the question is pretty well settled now in favour of the former. To make a good fish-joint, the surfaces of the bearing between the fish and the rail should fit perfectly, and be straight in section. There should be a slight space or clearance between the plate and the web of the rail to allow for variations in size, and also to get a proper bearing against the flanges. Fish-plates should be quite free from winding, and the holes in them should be large enough to prevent the bolts from binding in them. Fish-plates were used early in Germany, but not in the manner of a suspended joint between the supports. They were employed merely to hold the ends of the rails together in the chairs, and were adopted in this manner on the Leipzic and Dresden railways, and other lines in Rhenish Prussia. The gauge was kept in place by the use of long bolts or tie-rods passing through the sleepers.

6162.



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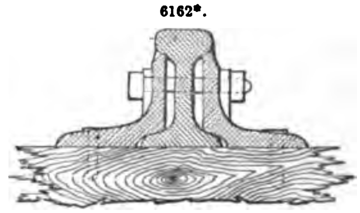

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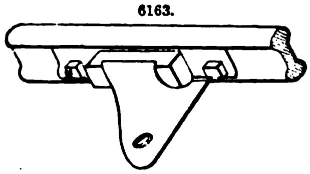

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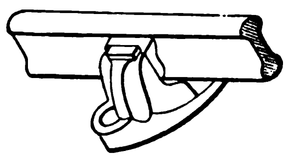
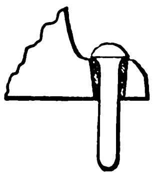


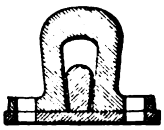
6165.



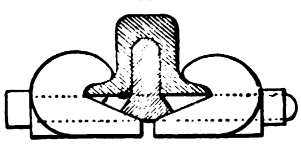
In addition to chairs and other methods of attaching rails to the sleepers, W. B. Adams designed a fastening on the principle of the bracket or ship's knee. It is adapted for the double-headed rail, Fig. 6162, but can be used also for the foot rail or single-headed, Fig. 6162*. It will be seen that the fish and chair are entirely abandoned, the rail being fixed on the sleeper, or let into it, or placed above it, so as to be wedged below if preferred. The rail is secured in position by the application of knees or brackets, bolted to the rails and passing through them, and to the sleeper also, precisely as a deck beam is fastened to the side framing of a ship. This arrangement fulfils the conditions of keeping the rail as low as possible on the sleeper, about 2 in. lower than the ordinary chair, and of saving the lower table from damage by blows, while the even top does not interfere with its being firmly fixed when reversed, so that it is really a reversible rail. There are no keys to get loose, and the bolts are saved from much vibration by the structure being bedded on the timber. The joint-brackets are 1 ft. 6 in. in length, with four bolts, and weigh from 42 lbs. to 45 lbs. a pair. The intermediate brackets are 4 in. long, with one bolt, and weigh 12 lbs. a pair. These brackets are in partial use on the Great Northern, South-Western, and Western Railways of France. Greaves subsequently introduced some improvements in his joints and fastenings. A joint-chair is shown in Fig. 6163, in which he places one fish in the rail channel in the ordinary joint-chair, and secures it by a wood key, also by bolting it down externally to the rail. In Fig. 6164 a chair with a circular base has a plate to fill the bottom of the rail, and a vertical wood key to secure it. A method is also shown in Fig. 6165 for preventing the head of a chair-spike wearing, by surrounding it with a ferule of wood.

The first joint designed for the bridge rail, as shown in Fig. 6166, was not considered effective enough to constitute the rail a beam fixed at the ends, so W. B. Adams designed the sample in Fig. 6167. It consists of a pair of side castings, each 12 in. long, which press in the angle formed by the rails and the side flanges. An iron tongue piece, also 12 in. long, fills the hollow of the rail. A couple of bolts ⅞ in. in diameter pass through the three castings, and, as they tighten, the side castings compress in the inclined plane where they join, and produce a firm joint. This truss-joint has been tried partially on lines in Ireland, upon which the bridge rail is laid down. The number of separate castings necessary to form the chair is an objectionable feature in the arrangement, not to mention the nicety of fitting requisite to make a really good joint. The remarks made respecting suspended and supported joints, hold good for the bridge section of rail as well as for those of other forms, provided they are laid upon cross sleepers. Under these conditions, each chair acts the part of an anvil, while the engine is the hammer, and the result is that when supported joints are subjected for some time to this kind of action, they become hammered out and spread.

6166.

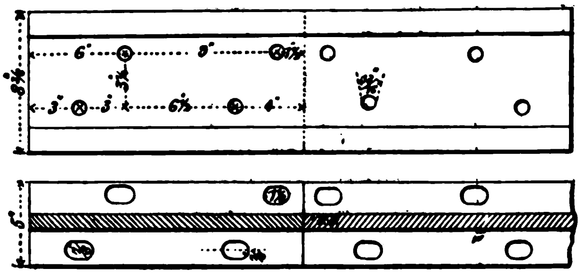


6167.



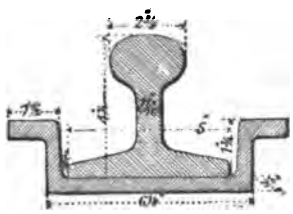
In Figs. 6168 to 6170 is represented a trough-shaped chair. Fig. 6168 is a plan of the joint-chair; Fig. 6169, a plan of the ends of the rails with the heads removed; and Fig. 6170, a cross-section of both chair and rail. This class of rail-joint is well adapted for the single-headed rail in question, and was designed by Blakiston for a portion of the Ulster Railway, and secures the joint upon a principle different to that in ordinary use. Usually the joint is fished laterally instead of at the bottom. On referring to the cuts, it will be seen that, in order to allow for the expansion and

6168.



6169.

6170.



contraction at the joints, the holes in the rail are of an oval shape, and a fraction larger, both longitudinally and transversely, than the corresponding holes in the chair. The latter is a complete trough girder, and its breaking weight could be readily calculated on that assumption. The ribs at the side impart great lateral stiffness to it. The weight of the rail is 75 lbs. to the yard, and that of the chair, which is 2 ft. 9 in. in length, is 45 lbs. This is not too heavy proportionately for the rail. It was a mistake, frequently committed in former times, of making the chairs considerably too light for the rails they had to support. Breakages were continually occurring; in consequence John Ramsbottom introduced on the London and North-Western Railway a wrought-iron chair and fish-joint without bolts, in which a wrought-iron key is used, which is long enough to reach from chair to chair, and is placed on each side of the joint. This method of suspending the rail from the chair has the advantage of maintaining the rail uninjured by the chair, so that it can be turned with better results than usual. It also saves the expense of punching or drilling the bolt-holes in the rails, but this is more than compensated by the additional length of the key. Iron keys might be in some instances substituted for those of wood in hot climates with advantage.

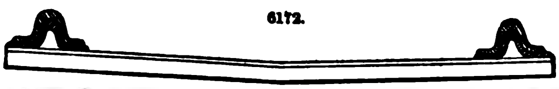
It has been asserted on good authority that the compressed keys are not the best which can be used in India and other similarly situated countries. After being exposed to the action of the weather for some length of time, they swell and require to be pared down, before they can be made to fit into the chair. But since these objections were raised, which were no doubt valid, the keys for railways in India have been made of rather larger scantling than those for the English lines. They are not then so readily affected, and have been found to afford very good and satisfactory results. A very superior description of key is employed on the Portuguese lines. It is made of oak, about 10 in. in length, and has a slight taper longitudinally, so that, as the wood shrinks by reason of the heat, the key can be driven up, and the rails tightened in the chairs.

A certain amount of elasticity is necessary in the material of which keys are made, or the cast-iron sleepers would break under the passage of a heavy load at a high speed. Barlow was well aware of this fact when he tried his wrought-iron key, shown in Fig. 6147, the thickness of which was proportioned, so that, while on the one hand the key had sufficient elasticity, on the other it was not too strong for the chair. The best laid road with the heaviest rails will be shaky to run over, if the keys do not fit well and tightly.

Rails.—The earliest, cheapest, and worst description of wrought-iron rail is the flat tire-bar rail spiked down to a longitudinal balk. This was used on some of the early American lines, but subsequently abandoned on account of the great wear and tear, and the danger to passengers. Sometimes the end of the rail turned up, broke through the bottom of the carriage, and killed a person. This form was succeeded by the single T fish-bellied rail, weighing from 28 lbs. to 35 lbs. to the yard, which was used on the Liverpool and Manchester line. The Vignoles' rail came next, then the double T, then the foot rail, the bridge form, and others, which will be noticed in their proper place. After a few alterations in form and weight Barlow's rail was reduced to the section shown in Fig. 6171. A plan and cross-section of the line laid with these rails are given in Figs. 6172, 6173. This rail was invented to dispense with the assistance of sleepers, and to take its own bearing in the ballast. It weighed at one time as much as 127 lbs. to the yard, but this weight has subsequently been reduced to about 95 lbs. The width was originally 13 in., and the height 5¾ in., but these dimensions were altered to 11 in. and 4½ in. as in Fig. 6171. The joint is made by placing the end of the rails on a saddle of wrought iron 2 ft. 6 in. in length, and made to fit the hollow of the rail. The ends of the rails are riveted to the saddle without allowing any room for contraction and expansion. Since the upper part of the rails abut closely against each other, they resemble the upper flange of a girder, and are in compression, while the lower part is in tension similar to the bottom flange of a girder. The whole joint therefore represents a girder, the strength of which is altogether dependent upon the shearing strength of the rivets. With respect to expansion, it is evident that if any were to take place, the rails must either expand throughout their whole length, or else buckle laterally and become distorted. This question of the contraction and expansion of rails is not by any means satisfactorily settled. Brunel, who riveted some eighty or hundred rails together on the Great Western Railway, did not find that any inconvenience arose from no provision

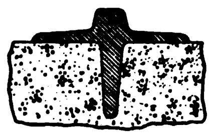
being made for expansion. It is probable that no expansion does occur in the case of the Barlow rails, for, as they lie directly on the ground, which is a good conductor, the heat is carried off, and

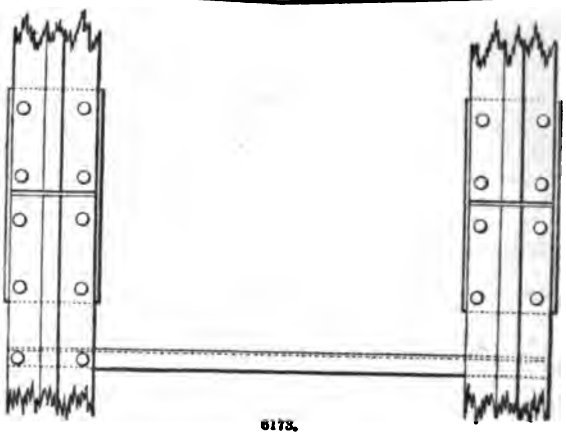
6172.



6171.

6174.



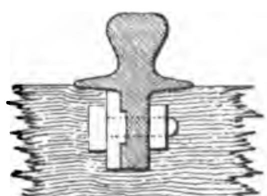


6173.

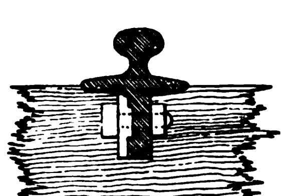
the rise in temperature of the rail prevented. The disadvantage common to all rails of this type is the impossibility of properly packing them. This objection is fatal to their general adoption. The Barlow rail has resulted in a complete failure, and the inventor was one of the first to acknowledge it. The objects to be gained by the saddle-back rails are lateral and vertical stiffness, combined with a large bearing surface. All these points can be equally well ensured in a rail of the section represented in Fig. 6174. A bearing surface can be readily obtained of 14 in. in width, in comparison with the Barlow rail of the same weight, of 9 in. in total depth and 6¼ in. in depth below the ballast. The joints can be formed by means of cheek-plates or wrappers bolted to the vertical and horizontal parts of the rail, and an allowance can be made for expansion, by making the bolt-holes in the rails larger than those in the cheek-plates. Any difficulty or extra expense which might occur in the manufacture of a rail of this section, would be easily surmounted by the large quantity ordered.

In Figs. 6175, 6176, two sections of girder rails, proposed by G. W. B. Adams, are represented. He describes them as a single-headed form with a pair of lateral supporting wings, superadded at the position of the neutral axis, or they may be considered as foot rails on the American plan, with a lower vertical rib superadded to give vertical stiffness, and keep the gauge without straining the holding-down spikes by the blows of the wheels. The example in Fig. 6176 is 4½ in. deep, 3½ in. wide, and weighs 42 lbs. to the yard. A joint-plate 1 ft. 6 in. in length, 2½ in. wide, and ½ in. thick, is secured to the rail ends by two bolts. The other example in Fig. 6175 weighs 65 lbs. a yard, is 5½ in. in depth, and 4 in. in width across the supporting wings. The rails are fixed in cross sleepers which are truly and accurately cut in a grooving machine. This renders the getting out of gauge of the track impossible. The heads of the rails shown in Figs. 6175, 6176, appear small, but they are quite large enough for the wheel tread, unless when enormous and unprofitable weights are run over them.

6175.



6176.

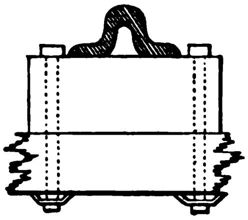


The bridge-shaped rails as shown in Fig. 6177, are considerably weaker, weight for weight, than the double I form. The proportion is as 5 to 7. Consequently a double T rail weighing 70 lbs., will be equally strong as one of the former type weighing 83 lbs. It is asserted that the bridge rail is not calculated to ensure soundness in the iron, as it requires iron of a superior description, and great care in rolling. Brunel, in some of his large contracts, in order to obviate the tendency of the rails to laminate, strongly advised his directors to pay an extra price to get them of good quality, which necessitated an additional process in the manufacture of them. Many engineers consider the system of the double I rail and cast-iron chairs to be much superior to the bridge rail, laid in any form. Hawkshaw abandoned the use of a rail weighing 58 lbs. to the yard having a form similar to the bridge rail, for the double I form and cast-iron chairs. The principal reason which will always prevent the bridge rail coming into extended use, is the difficulty of making a good joint, when it is laid in the usual manner with flat-soled joint-chairs, and especially when, in addition to the chair, the rail is fastened to longitudinal sleepers. It is almost impracticable to prevent the ends of the rails being driven into the timber when they are placed upon a flat plate. If the rails are fished, this difficulty is removed, but when fishing is resorted to, the double I rail

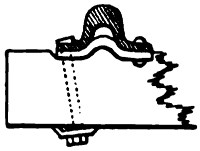
is to be preferred to any other form. In practice, rails must not be too high, or they offer too great a leverage for the effect of the lurch of the engine and carriages, which is occasionally a serious matter. Experiments have proved that when light rails have been put down, and subjected to a traffic beyond their powers of resistance, they become rolled out. Light rails placed in this situation, which were originally laid with a space of one-eighth of an inch at the joints, were found after being run over for some time, to be in close contact at those points.

As an example of the inferior manner in which the bridge rail was laid down in France, we will briefly refer to the permanent way of the Bordeaux Railway. The cross-sections of the rail and joint-plate are shown in Figs. 6177 to 6179. Both the average length and the cross-section of

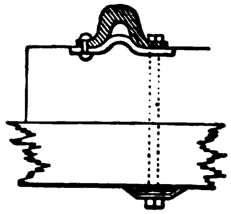
6177.



6178.



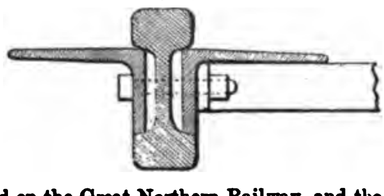
6179.



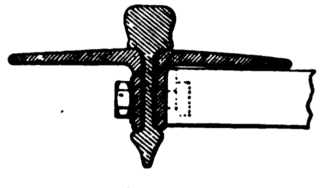
the longitudinal timbers, are only a little more than half those in use on the English lines. The sole chance of stability of a road, composed of such numerous short lengths of timber, must depend upon the substantial and workmanlike manner in which it is framed together. On the great western lines in France, this object is effected by the housing of the transoms into the longitudinal timbers, and by tie-bolts which pass through the latter and are firmly secured to the former. The continuous bearing of the longitudinal timbers is secured by a sort of dowel called a joint-plate, which practice has shown unites the ends of the timbers with a great degree of solidity. On the Bordeaux line, all the precautions which long experience in this country had proved to be necessary, were omitted. The short longitudinal timbers were merely laid end to end on the transoms as shown in Fig. 6177; the rails were laid on and riveted to the joint-plate, and the sole-tie between the outer and the inner rails was effected by the bolts which passed vertically through the rail, the longitudinal timber and the transom. The gauge of the road depended altogether upon the riveting of the rails, an operation which had been tried in this country and abandoned, as it led to many serious evils. The timbers could not be framed together until the rails were riveted, as the irregularities in their length and the great amount of expansion and contraction due to the climate, rendered useless any attempt at fitting without riveting. Moreover, the twisting and warping of the timber threw an undue strain upon the rails, which were not designed to bear so great a lateral strain. The tendency of the working of the traffic was to throw the line out of gauge, which was only resisted by the lateral stiffness of the rails, due to the riveting or to the holding-down bolts, which unfortunately acted at right angles to the disturbing force.

Figs. 6180, 6181, show two examples of Adams's suspended girder rail. The one in Fig. 6180 was

6180.



6181.



tried on the Great Northern Railway, and that in Fig. 6181 on the Bombay, Baroda, and Central India line. The fastenings of the two rails are similar, although the former is a double-headed and the latter a single-headed rail. The double-headed rail has heads deep enough to clear the wheel-flanges, and to allow for wear without allowing them to infringe upon the rail-bearers. The vertical rib connecting the two heads, being in a similar condition to the web of a plate girder, is made light. The object is not to sustain a load upon an insistent web, but to connect the top and bottom tables with such a total depth as will give the requisite strength, while the rail is suspended beneath the upper table, and forms a keel below the beams, giving a firm surface-hold in the ballast. The total depth of the rail is 7 in., the heads or tables being 1⅝ in. in depth and 2 in. in width. This gives practically as much bearing surface to the wheel as the ordinary double I rail of 2¼ in in breadth, because when by wear more than 1⅝ in. of width comes into bearing, the sides, which resemble mouldings, crush down for want of support. The angle-brackets are bolted through the rails, and to them as well, and, by breaking joint with the rails, and with each other, produce a uniform strength throughout, while the rail being suspended, and not insistent, can be made much lighter than would be possible, were it supported on the lower table by the ordinary method. The angle-brackets are about 6¼ in. wide, and when bolted to the rail make up a total width of 13¼ in., which is equivalent to the bearing surface of a cross-sleeper road, with the sleepers 2 ft. 6 in. apart. Consequently, as the height of the rail-tread is only 2½ in. above the bearing on the ballast, and the keel below is 4½ in. in depth, the maximum security against rocking or other disturbance in the ballast is ensured.

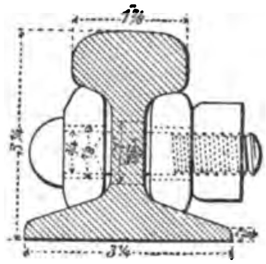
There are very few parts in this arrangement, which constitutes one of its best features. They

are the rail, the bracket, the bolt, and the tie-bar or transom, and these are all of the same material, that is, wrought iron. The bolts are comparatively but little strained, as the brackets fit securely in the square angles of the rail. There is a very large amount of lateral resistance to blows. Experiments were tried for comparing the strength of the joint of this rail with the fish-joint of the double I. The bearings were 7 ft. 6 in. apart. With a pressure of 8 tons applied by means of a hydraulic press, the bolts in the fish-joint were broken across, while those in the suspended girder joint stood 12 tons without any sign of yielding.

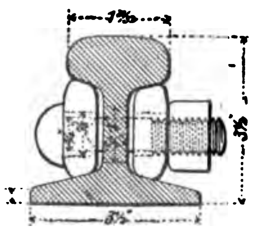
It may appear almost paradoxical to assert that too heavy a rail can be laid down, omitting all economical considerations. But experience has proved that there is a maximum limit. On the Eastern Counties line, rails weighing 95 lbs. to the yard, which had been laid, had to be taken up, and others weighing only 75 lbs. to the yard substituted for them. There were a great many more breakages with the heavier rail. Without going into needless particulars, the principal causes which tend to destroy rails, are the abrasion of the upper surface from the wear and tear of the traffic, and lamination or tendency to split off in layers, under the continual pressure of the wheels. Supposing the points of support for the rails, or the chairs and sleepers, to be 3 ft. apart, the heaviest weight they would have to bear, considered as girders, would be when the driving wheels of the largest locomotive in use were resting on them, which, for moderate traffic, would be equivalent to a weight of about 10 tons on the pair of rails, or 5 tons on one, acting at the middle of the rail, which is equal to double that weight uniformly distributed. Regarding the rail as a girder, the strain on the lower flange will be given—see MATERIALS OF CONSTRUCTION, STRENGTH OF—by the equation $S = \frac{W \times L}{8 \times D} = \frac{10 \times 3}{8 \times 0 \cdot 4} = 10$ tons nearly. Taking the safe strain at 4 tons to the square inch, the sectional area of either flange of the double-headed rail should not be less than $2\frac{1}{2}$ in., or of the whole rail about 7 in. These are the minimum theoretical dimensions. In practice the dimensions are very much larger. As a good general rule, not applicable, however, to rails subjected to a very heavy traffic, it may be stated that the weight of a yard of rail, if supported at intervals, should be 15 lbs. for each ton of the greatest load on one of the driving wheels of the engine.

In Figs. 6182 to 6190 are shown various sections of rails designed by Carl Sandberg, Inspector

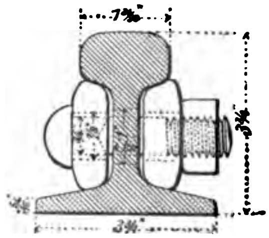
6182.



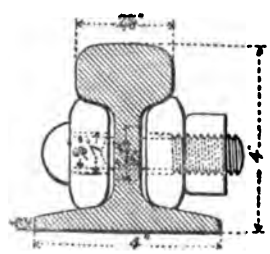
6183.



6184.



6185.



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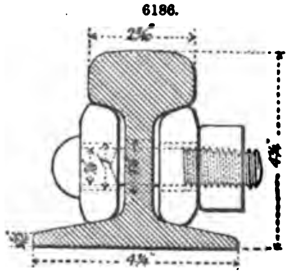
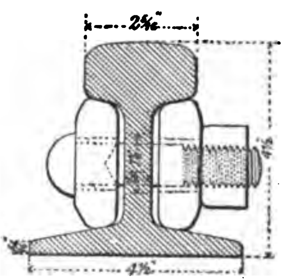
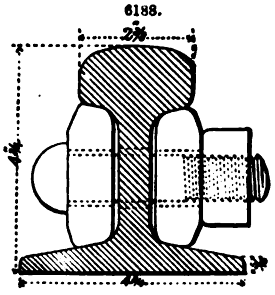


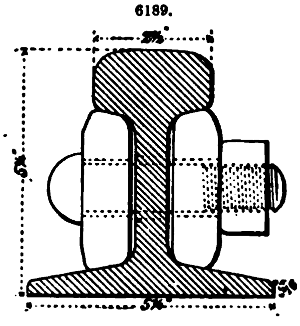
6187.



6188.

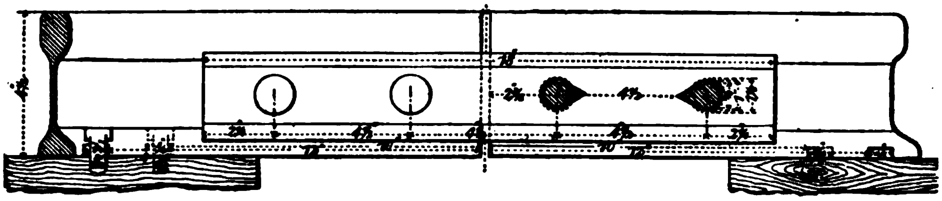


6189.



of Railway Plant to the Swedish Government. The peculiar features in these sections are that the width of the flange is equal to the height of the rail, thereby giving greater stability to the road,

6190.



that the fish-plates are reversible, and the angular inclination of the cheeks is such as not to throw too much work upon the bolts, giving a stronger joint than can be otherwise obtained, with a pear-shaped rail-head, and that the material is distributed in the different portions of the rail, exactly according to the requirements of each part. Thus a good wearing surface is provided for the heads, while the web possesses the requisite stiffness, and the flange has sufficient strength and stability. The dimensions and details of the sections in Figs. 6182 to 6190 are given in the accompanying Table I. The joint is shown in Fig. 6190 for a rail weighing 65 lbs. to the yard.

TABLE I.

Weight in lbs. a yard.	Width of Flange and Height of Rail in inches.	Width of Rail-head in inches.	Thickness of Head in inches.	Thickness of Stem in inches.	Thickness of Top Slab in the Rail Pile in inches.
40	$3\frac{1}{4}$	$1\frac{7}{8}$	$\frac{7}{8}$	$\frac{1}{2}$	6×2
45	$3\frac{1}{2}$	$\frac{31}{32}$	$\frac{15}{16}$	$\frac{1}{2}$	6×2
50	$3\frac{3}{4}$	$\frac{31}{32}$	1	$\frac{1}{2}$	7×2
55	4	$2\frac{1}{8}$	1	$\frac{9}{16}$	7×2
60	$4\frac{1}{4}$	$2\frac{3}{16}$	$1\frac{1}{8}$	$\frac{9}{16}$	8×2
65	$4\frac{1}{2}$	$2\frac{5}{16}$	$1\frac{3}{16}$	$\frac{9}{16}$	8×2
70	$4\frac{3}{4}$	$2\frac{3}{8}$	$1\frac{3}{16}$	$\frac{9}{16}$	$8 \times 2\frac{1}{4}$
75	5	$2\frac{7}{16}$	$1\frac{1}{4}$	$\frac{9}{16}$	$8 \times 2\frac{1}{4}$
80	$5\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{1}{4}$	$\frac{9}{16}$	$9 \times 2\frac{1}{4}$

The system of testing rails is variously carried out by different engineers. Sandberg proposes the following, which is very satisfactory. The supports should consist of solid iron blocks, 4 ft. apart, and the weight, of a ball weighing half a ton. The weight should fall on the head of the rail, weighing 40 lbs. to the yard, Fig. 6182, from a height of 4 ft., and for those weighing an additional 5 lbs. a yard, the increase of fall should be 6 in., so that the fall proper for a rail weighing 80 lbs. to the yard would be 8 ft. Out of every 1000 rails one rail should, at least, be tested, and if not broken, the whole 1000 may be accepted; but if broken, ten rails must be tested from the same make, and for every one of these standing the test, ninety-nine may be accepted.

With the exception of the Great Western and a few other lines, the double-headed rail is almost universally used in England. The accompanying Table II. shows the section of rails most generally employed in different countries.

TABLE II.

Name of Country.	Section of Rail.	Name of Country.	Section of Rail.
America	Single-headed.	France	Single-headed.
Australia	Double-headed.	Germany	Deep flange rail.
Austria	Deep flange rail.	India	Double-headed.
Brazil	Double-headed.	Italy	Deep flange rail.
Canada	{Single-headed. Bridge rail.	Ireland	Bridge rail.
		Naples	Single-headed.
Ceylon	Single-headed.	Peru	" "
Chili	" "	Prussia	Deep flange rail.
Denmark	Deep flange rail.	Russia	" "
Egypt	Double-headed.	Sardinia	Single-headed.
England	" "	Sweden	Deep flange rail.

It is worthy of remark that the double-headed rail was originally laid down in France and on the Rhenish railways, but latterly the preference has been given to the single-headed form. The bridge rail has also been employed on Brunel's system, and Barlow's rail has been introduced as well on those lines.

Steel Rails.—The increased weight of the engines lately constructed, together with the high speed at which they run, have led to the rapid destruction of the iron rail, and has rendered it highly desirable to resort to steel rails, which are being rapidly introduced on our principal lines

of railways. A steel rail, if hard, should be homogeneous in texture. If hard in some places and soft in others, it is liable to be broken by blows. The value of the steel rail consists chiefly in its being homogeneous, being rolled from a single ingot, without a weld. On the other hand, the iron rail is analogous to a bar of scrap iron, a mass of imperfect welding, on which scale causes want of homogeneity. The chief cause of the destruction of iron rails is not the actual attrition, but the disintegration, which results from repeated blows. When a blow of a certain intensity is given, the iron rail disintegrates, but the steel rail does not. A steel rail of about 85 lbs. to the yard may be fairly regarded as affording the maximum amount of strength, rigidity, and durability that the requirements of locomotive traffic demand.

The operation of rolling cast steel ingots into finished rails has very recently been successfully accomplished by the Philadelphia and Reading Railway Company. The steel was made at the Mid Vale Steel Works, near Philadelphia. It was cast into ingots about 9 in. square, and furnished to the rolling mill to be heated and rolled into rails, weighing 68 lbs. to the yard. The rolling was done by the same rolls which were in ordinary use for the rolling of iron rails. This is a great advantage, as it is an expensive affair to construct new and special rolls unless for a very large order.

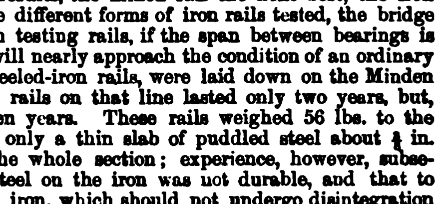
The manufacture of steel rails by the Bessemer process encourages the hope, that at length a material has been obtained, which will be able to withstand successfully the wear and tear, which so rapidly destroys its wrought-iron predecessor. About ten years ago, some steel rails were laid down at the Camden Town and Crewe stations of the London and North-Western Railway, where the traffic is of a character so exceptionally heavy, as to wear out iron rails in the course of a few months. A couple of steel rails 21 ft. in length were laid down at the Chalk Farm Bridge, side by side with two ordinary iron rails. When taken up three years afterwards, after outlasting sixteen faces of the iron rails, they were evenly worn on the one face which was alone exposed to a depth of about one-quarter of an inch, and were still capable of being of service. The adoption of steel rails on main lines, where the traffic is sufficiently heavy to justify the expense of laying them down, will prove cheaper in the end, will diminish the breaking up of the road, and add to the safety of the public.

The cost a ton of steel rails is nearly double that of the ordinary iron rails, but if we put the life of the latter at three years, and that of the former at eight, the disproportion in price disappears.

In Fig. 6191 is represented the section of the Bessemer steel rail made for the Great Indian Peninsular Railway. The weight of the rail is 86 lbs. to the yard. From an extensive series of experiments undertaken to ascertain the relative strengths of steel rails, iron rails steeled on the face, and iron rails, the steel rails gave the best results, the mixed rail the next best, the iron the worst. It should be remarked that of all the different forms of iron rails tested, the bridge form was considerably weaker than the others. In testing rails, if the span between bearings is made twelve times the depth of the rail, the latter will nearly approach the condition of an ordinary solid web girder. The first steel rails, or rather steeled-iron rails, were laid down on the Minden and Cologne Railway, in 1854. The original iron rails on that line lasted only two years, but, by steeling the head, the mixed rail lasted eleven years. These rails weighed 56 lbs. to the yard, and the steel used in the manufacture was only a thin slab of puddled steel about ½ in. The steel portion formed only 12½ per cent. of the whole section; experience, however, subsequently showed that this mere facing of cast steel on the iron was not durable, and that to produce a complete combination of cast steel and iron, which should not undergo disintegration by the vibration of the rail, it was necessary to have as a minimum 47½ per cent. of the section, of steel. Under these circumstances, it would be better to employ the Bessemer rail wholly of steel.

In order to ascertain the relative advantages of steel and iron rails, the directors of the Furness and Midland Railway had a series of tests carried out. For this purpose, steel rails of 73 lbs. to the yard of the section in Fig. 6192, and iron rails of 80 lbs. to the yard of the section in Fig. 6193, were keyed in chairs, placed 4 ft. from centre to centre, with the following results;—The steel rails supported a weight of 5 cwt. falling 20 ft. and 26 ft. respectively, while the iron rails broke with the same weight falling 6 ft. and 8 ft. These trials were considered to establish the superiority of the steel rails, and the whole Furness and Midland Railway was relaid with them.

6191. 6192. 6193. 6194.



With respect to steeling the top surface of rails, Dod's process was employed with success more than ten years ago. A steel-headed rail is shown in Fig. 6194, which presents some features of novelty.

It is the invention of L. Booth, of Rochester, U.S., and has already been tested in the United States. In making these rails the iron rail is first rolled to the required form. The cap of steel, also rolled to the proper dimensions and the same length as the rail, is then heated moderately, placed on the rail, and the whole is passed through a machine, by which the sides of the cap are firmly closed on the iron; and it is claimed by the inventor, that the squeezing out of the top by the tread of passing trains, causes the cap to fold round the rail, so to speak, and take a firm hold. The first rails tried were put down on a branch of the Pennsylvania Central Railroad. One rail was 28 ft. in length, and the steel cap, not being quite closed in upon the sides, was so loose that it could be easily driven off endwise with a hammer. It was put down where a heavy engine was frequently passing over it, drawing truckloads of iron. The effect was to shift the cap endwise with the moving train, until it struck the adjoining rail, and as the train returned the cap would be carried along as far in the other direction. This effect continued from day to day,

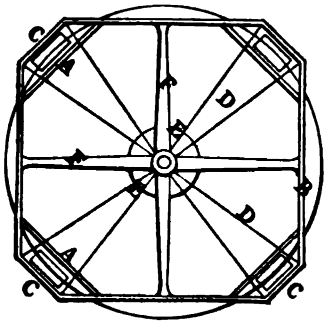
but soon began to abate by degrees, until in three weeks the end action ceased, and the cap began to clinch the head of iron, first at the ends, then approaching the centre, until in the short period of ninety days the entire rail became as solid and firm as if made of one piece of steel, and striking the head with a hammer would meet with reaction equal to striking any piece of iron or steel of the same weight.

Testing Rails.—With the increase in the weight of rails, and consequently in their cost, there is the greater necessity that they should be of good quality, and able to withstand any test of a fair and practical character. Price has recently designed a machine for this express purpose, which tests both the strength of the rail and its powers of resistance with regard to wear and tear.

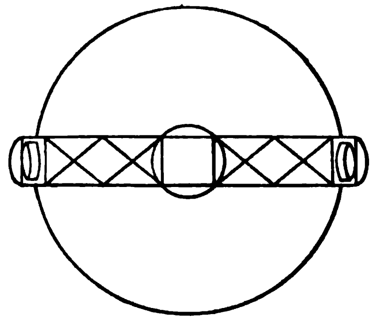
The various existing methods of testing rails may all be reduced to one of three heads, namely, a dead-weight test, a falling-weight test, and an examination of the section of fracture. The test by a dead weight determines the strength of a rail as a girder, but that is all. The endeavour to ascertain whether a rail has sufficient toughness by submitting it to the action of a falling weight is fallacious, since by its use, rails of a good serviceable quality may be rejected, while bad ones may be passed.

To a practised eye the appearance of the fracture, and that of the planed section after treatment with acid, may be some criterion of the quality and properties of the material, but it is not of a character sufficiently tangible to be inserted in a specification. The machine in question is intended to determine with accuracy, the strength and wearing capabilities of rails both of iron and steel. It consists of a simple arrangement of two or more metal or steel rollers supporting a circular frame which confines them. The frame is connected by radii with a central boss, through which passes a vertical axle, shown in Fig. 6195; or the frame may be cruciform for four rollers, as in Fig. 6196. Another arrangement is shown in Fig. 6197, in which a simple beam passes across the centre for two rollers. In every case, sufficient strength is given to the arms or radii to resist the centrifugal force when revolving.

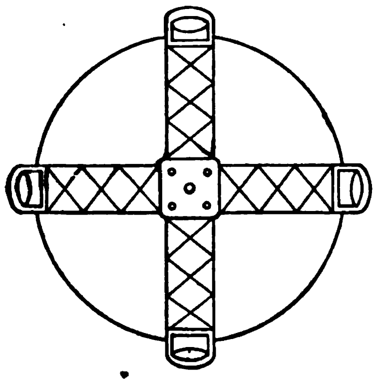
6195.



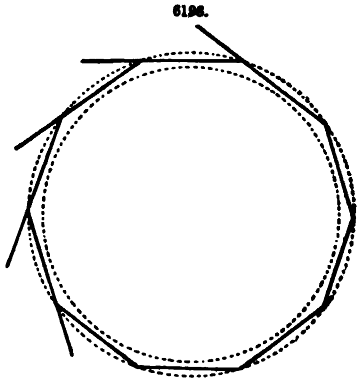
6197.



6196.



6198.



The rails to be tested are formed into a circle or polygon, and are supported on sleepers packed up with ballast in the usual manner. This arrangement constitutes the road under the rollers, upon which they are caused to travel at any required speed, by means of motion communicated to the centre axle from shafting underneath, or by direct action of a pair of cylinders. The frame is sufficiently stiff to bear entirely on the rollers, and the boss is free to move up and down on the vertical axis, so that the machine may adapt itself readily to the inequalities of the road.

The weight with which each roller bears upon the rails, should be equal to the weight on the driving wheel of the heaviest engine likely to be worked over the same rails, when in actual use. The rollers have treads sufficiently wide to work over the rails, arranged as a polygon, as in Fig. 6195, and being portions of cones radiating to the centre at the level of the top of the rails, see Fig. 6198, they will traverse over a polygon as easily as along a curve.

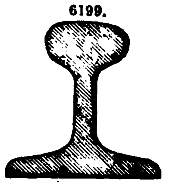
In using the machine to test the strength of rails, some of the sleepers are left out at several

parts of the circle, so that the rails at those places may span double intervals. If a rail takes a set, or breaks under the action of the revolving rollers, it is unfit for use. In order to arrive at a proper margin of strength, the lower member is weakened by cutting or drilling until it breaks. By testing rails of known good quality in a similar manner, a standard of strength may be arrived at. The determination of the wearing properties of a rail, is manifestly accomplished by keeping the machine revolving until the rails are worn out. In all experiments with this machine, Price assumed the truth of the law first demonstrated by Price Williams, according to which, rails are worn out by the action of a certain number of speed tons. Upon this assumption, if ten rails are placed together under the machine, one of which is a standard, it may be accepted that those which wear out before the standard, are inferior to it in quality, and also that those which wear out first are the worst, and that the number of speed tons borne by each is the measure of its value. The wearing effect produced by a machine having four rollers, bearing with a pressure of 7 tons each upon a ring of rails 40 ft. in diameter, and worked at a speed of 40 miles an hour, may be thus estimated;—42 revolutions a mile × 40 miles an hour × 22 hours × 28 tons = 1,034,880 tons a day of 22 hours, allowing 2 hours out of every 24 hours for oiling, packing, and attendance. The total result would be equal to 41,395,200 speed tons a day. A couple of days' work would discover any defective rails, if not, destroy the test.

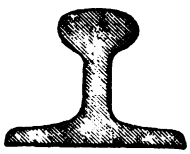
The machine shown in Figs. 6195 to 6198 consists of a horizontal beam, supported on a pair of metal rollers 5 ft. in mean diameter and 16 in. wide. The circle traversed is 40 ft. in diameter. The rollers weigh 2¼ tons each, and, with the beam weighing 6½ tons, the pair of rollers press on the rails with a total weight of 11 tons. One roller bears with 5 tons pressure, and the other with 6 tons. Motion is imparted to the central vertical axle by means of shafting underneath and bevelled wheel and pinion driven by a steam-engine. The power is sufficient to get up a speed of 20 miles an hour, and a counter is employed to register the revolutions.

From experiments made by Price, it appears that iron and steel rails are very differently acted upon by rolling weights. A steel rail of the section shown in Fig. 6199, weighing 80 lbs. to the yard, and an iron rail, shown in section in Fig. 6200, were tested. Strips were cut from the flanges of both of the rails, and subjected to direct tensile strain. The steel bore 30 tons a square inch before fracture, and stretched 20 per cent. of its length, and was then so tough as to bend double cold. The iron bore only 21 tons a square inch, and stretched only 9 per cent. This indi-

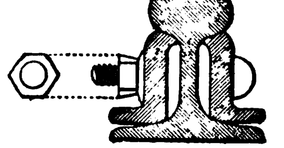
6199.



6209



6201.



cates that steel, though stronger and apparently tougher under slowly applied strain, is really more brittle than iron under strain suddenly applied, as if the molecules of steel required time to arrange themselves to resist separation. It is to be remarked that all the ordinary types of fish-plates break under this machine. Those with a small flange below as shown in Fig. 6201, alone stand under its action. The rails also show a weakness at the fish-holes. The life of an ordinary iron rail of fair average make, is by this concentrated method of rolling test, equal to not less than 30,000,000 speed tons.

In Figs. 6195 to 6198 A are the rollers, B the beams, C the castings to receive the journals, D the tie-rods, E the bevel driving wheel, and F the driving arms.

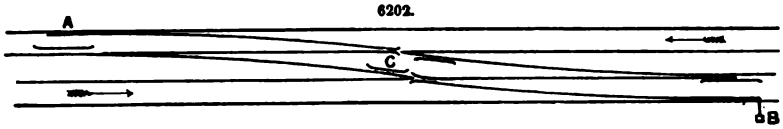
Switches, Points, and Crossings.—When a train or single carriage is obliged to leave one pair of metals and run on to another, some contrivance is necessary, in order to effect the transit without interfering with the normal condition of the road. The simplest method of conducting this operation, and one which is always used on contractors' or temporary roads, is to nick the rails at the crossing, or the point where the one pair of rails crosses the other, in order to allow the flanges of the wheels to pass, and to leave about a couple of feet of the ends of the rails loose, that is, held only to the sleeper by a loose working spike or pin, at the place where the junction terminates. By simply moving these loose ends of rails backwards and forwards, the carriages are turned from one pair of rails to the other, or shunted, as the technical phrase is. This crude arrangement will not answer for steam traffic, and it is therefore necessary to provide some better means for accomplishing the shunting. It would be to little purpose to mention a tithe of the numerous railway switches and crossings which have been invented, with the object of facilitating and rendering safe the process of shunting. The principal features will be alluded to, and a sufficient number of examples given to illustrate what constitutes a very important part of the permanent way of a line, especially with reference to the cost of maintenance. One of the early switches was Fox's, in which the outer rail was cut or notched out, for the purpose of admitting the tapered point of the tongue rail when closed, and for lessening the projection presented to the flange of the wheel in running against the points. In some of the switches used on the Great Western line the outer rail is slightly bent at the extremity, so as to form a recess against the end of the next rail, which recess receives the point of the tongue rail, and answers the same purpose as the notch in Fox's switch.

Before proceeding to details it will be well to describe generally the mode by which trains can be transferred from one line to the other while in motion.

The apparatus in common use for this purpose consists of two parts, known as the switch and the points, an example of the simplest form of which, or a single switch, is shown in Fig. 6202. The switch B is made of a movable rail or tongue, tapered at the end so as to lie close to the

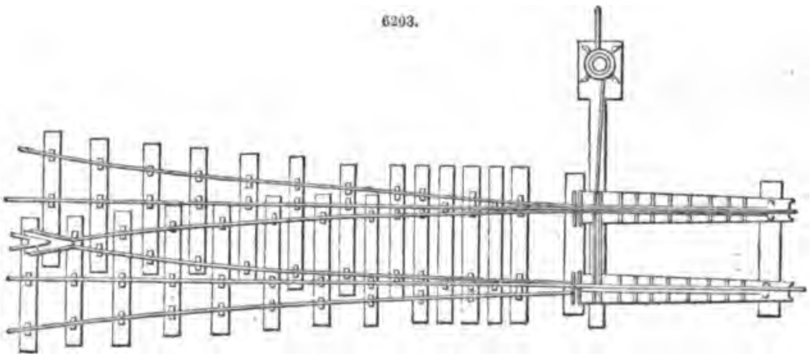
main rail, or to be pushed out from it sufficiently far to enable the flange of the wheel to pass in between them.

6202.



To move the switches, and also to allow them to be, under certain circumstances, self-acting, a lever is employed, having a counterweight acting inside the switch-box, at B in Fig. 6202, which is placed alongside the line with the lever handle projecting. The switches are arranged so that the main line is always kept open, when the lever is not moved. This self-acting adjustment of the lever and switch is not applicable at the entrances of large stations, and special arrangements are provided in such cases. The points C, or crossings, are fixed V-shaped pieces of iron, where one line of rails crosses the other, and are made of iron or steel of superior quality, as they are exposed to an immense amount of wear and tear. The short lines at the points C, parallel to the rails, are check or guard rails, and are intended to prevent any tendency of the wheels to leave the metals. The direction of the traffic up and down is shown by the arrows, that is, it is in the direction to which the V of the crossing points. Were the direction of the traffic reversed, the point of the V would meet the traffic, and the points would be what are termed facing points. These are highly objectionable, and strongly protested against by the Government inspectors of railways, as being a fruitful source of danger and accidents. The danger increases with the speed. In Fig. 6203 is represented the general plan of a three-throw switch. By this arrangement the single line of rails is moved by the switch, which shifts both rails together to any one of the three diverging lines.

6203.

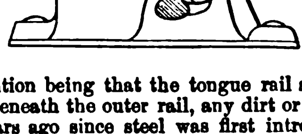


The direction of a train may be reversed, where room permits, by laying in a couple of sidings converging to each other, with a piece of straight at their point of meeting. Traversing platforms are also used for transferring engines or single carriages from one line to another parallel to it.

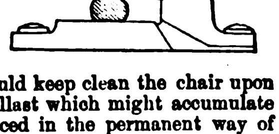
The weakest places in switches and crossings are those in the outer rails of switches, and the wing rails of the crossings, in the line where the outer edge of the wheels crosses them in a diagonal direction. These parts are exposed to a series of severe blows from the wheels, caused to a great degree by the undulation of the rails, while the train is passing over, the weight of which is sustained alternately by the point rail and the outer rail. The moving or shifting of the various parts of a switch or crossing, which results from this cause, is very injurious, as the least settlement of the rail on which the wheel is running, causes the infliction of a severe blow. In situations in which the traffic is heavy, these parts of the permanent way suffer a very large amount of wear and tear, especially in places where the brake is frequently applied.

In Figs. 6204, 6205, are shown sections of Parsons and Baynes' switch. In the former, the point rails for crossings and the tongue rails for switches were first made solid. This is a good plan, but they do not afford protection to the outer and wing rails which are the most liable to suffer abrasion and concussion. In Baynes' switch there is a deep tongue rail, the seating of which is lower than that of the outer or main rail, the intention being that the tongue rail should keep clean the chair upon which it slides by pushing off, beneath the outer rail, any dirt or ballast which might accumulate there. It is nearly twenty years ago since steel was first introduced in the permanent way of railways. A rail with a welded upper surface of steel was laid down in the goods station of the Great Northern Railway at King's Cross, to form the outer rail of a three-throw switch. The steel surface was 1½ in. in width by ½ in. deep. It was laid down at a spot where the traffic was

6204.



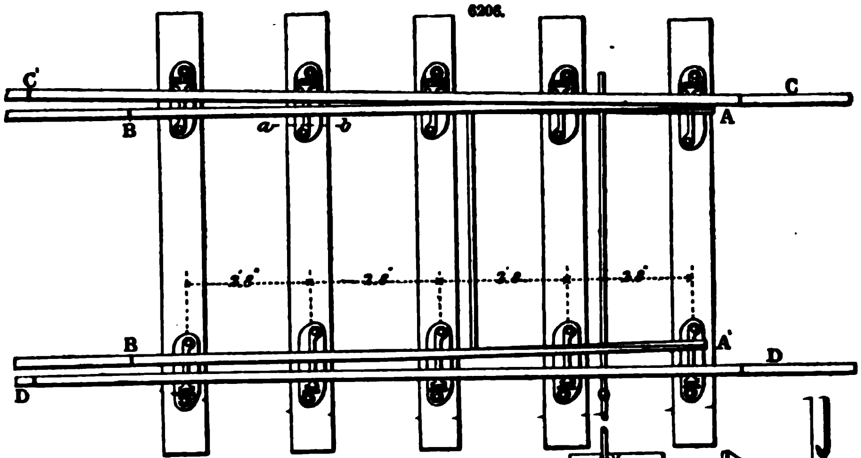
6205.

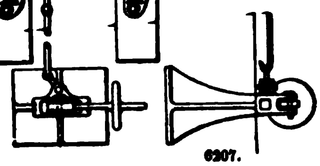


heavy, and the result was that after six months' wear and tear the upper table of the rail for a length of 3 ft. was crushed down and splintered. This proves that the hardest material will suffer from the cutting action, and that rails will eventually be grooved out in a similar manner. Referring to Figs. 6204, 6205, it will be seen that if the tire of a wheel is worn hollow, it will, when running over a switch or a crossing, be actually lifted off the inner rail and carried on the adjoining rail, resting only upon the outer edge of the tire. It is just at this moment that the blow takes effect, which causes a lateral strain upon the wheel and channels or grooves out the rail along the path of the outer edge of the tire. It follows, therefore, that when a wheel which has a worn tire passes over a new switch or crossing, it receives a severe blow on its outer edge, because the section of the tire is not adapted to that of the two new rails. On the other hand, when a new tire passes over an old worn switch or crossing, a similar result ensues, although the blow is then given by a different part of the tire.

In Figs. 6206 to 6208 are shown one of Ransomes and Rapier's most improved form of switches

6206.

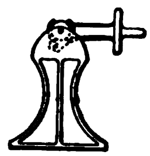




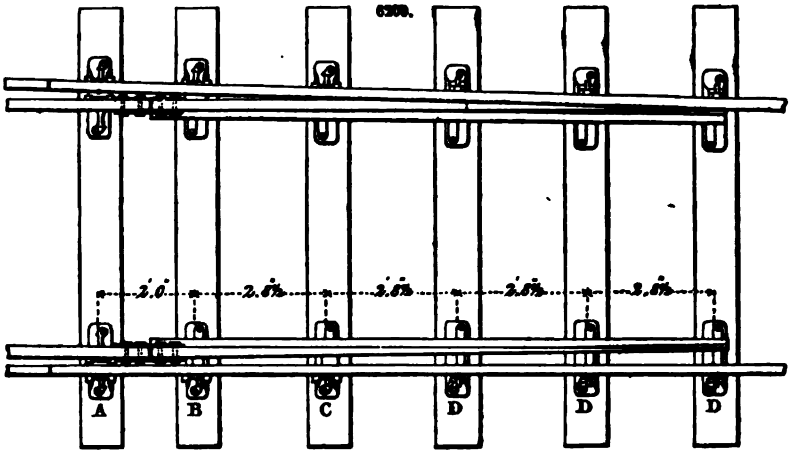
6207.

for the ordinary double-headed rail. The switch, or movable part of the rails, comprises the length included between the points A and A', and the heel of the switch at B, B', in Fig. 6206, in which the switch is set so as to shunt the train on to a pair of metals situated to the left of the rails C, C', and A', B', supposing the train to be advancing on the right of the figure. The tongues and stock rails may be of any length that may be desired. In Figs. 6207, 6208, are represented the details of the switch-box, all of which are self-explanatory. When the traffic is light, the tongues may be of steel and the stock rails of iron, which make a very durable and economical switch. The distance-rods can be arranged so as to

6208.



6209.

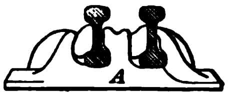


6217.

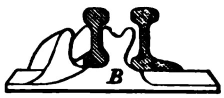
pass through both stock rails, and thus prevent the tongues lifting during the passage of the train. The connecting rods nearest the points can be made so as to enable the points to be padlocked

to either side. A switch by the same makers, with an improved form of tongue, is shown in Figs. 6209 to 6217. Greater lateral stiffness is thus imparted to the tongues, which are well adapted

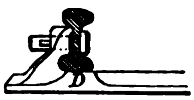
6210.



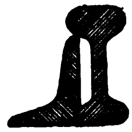
6212.



6214.

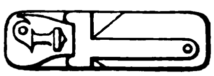


6216.



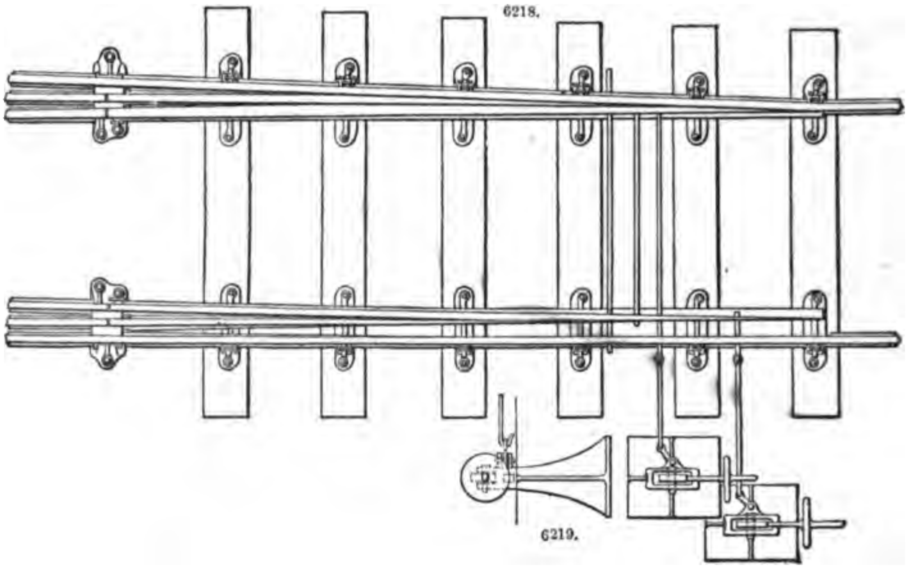
6211.

6213.



6215.

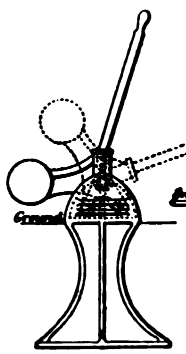
6218.



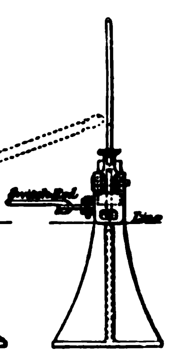
6219.

for single-headed rails. The details of the lever and connecting rods are given in Fig. 6217, and the cross-sections and plans at the points indicated by the corresponding letters in Figs. 6210 to 6216. The usual length of the stock rail is 15 ft., and of the tongue 12 ft., but other lengths can be employed as well. In this example the switch is fished at the heel instead of resting on a heel-chair as in the former. A detail drawing of a three-throw switch, of which a general plan was shown in Fig. 6203, is shown in Figs. 6218, 6219. It is suitable for rails of either the double-headed or the Vignoles' shape, and is made either of iron or steel. Instead of one junction with the main line, a couple are made by means of this switch. It is of great use sometimes for the man in charge to know which way the switch is set, which can be managed by means of an indicator.

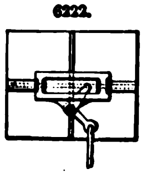
6220.



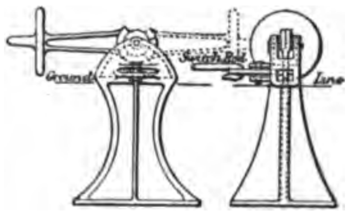
6221.



6222.



6223. 6224.



In Figs. 6220 to 6224 a very good example of switch-box, by Deas and Rapier, is represented, which possesses several advantages. The boxes are so constructed that they can be either planted in the ground as in the figures, or bolted on to the end of the switch-sleepers, and as well as the levers are all fitted up to gauges, so that the rigid and turnover handles are interchangeable.

As compared with an ordinary underground box, the following advantages belong to the example selected;—

Including the handle and switch-rod, the whole number of pieces is six, as against about fifty, and the liability to derangement is in the same proportion.

The handle pulls parallel with the road, and therefore takes up less room and is safer, and, together with weight, is so arranged that the pointsman can bring his whole weight on the switches, with the most perfect ease to himself.

It is not liable to be deranged by frost, which is a fruitful source of accident in the cesspool boxes, and is very useful for shunting purposes, as the handle can be set so as to hold the switches either way, and if an engine or wagon runs out of the switches, they always recover close home to the side on which they were last placed by the pointsman.

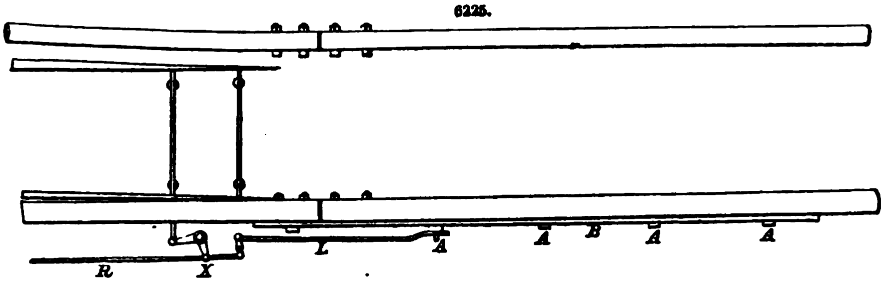
For goods yards and sorting sidings this is of very great value, as it enables one pointsman to manage several switch-handles with far less fatigue to himself, and also with much greater certainty, and consequent safety and saving of time in arranging trains.

The disc balance-weight faces the driver, and the front and back are painted red and white so as to show which way the switches are set.

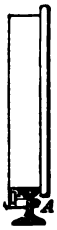
Every switch-box is both right and left hand, by simply taking out the bell-crank and turning it over.

It is evident that the points, having been once set for the transit of an approaching train, the next step is to ensure their complete immovability during its passage. This has been accomplished by a variety of locking apparatus under the control of the signalman, which, however, is only one step removed, so far as safety is concerned, from the old plan, where the pointsman simply holds the lever until the train has passed, when it springs back to its original position upon his quitting his hold, drawing the points with it. So long, therefore, as the immovability of the points during the transit of a train is at the option of the pointsman, any carelessness or negligence on his part might allow them to fail in performing this essential duty, and the result would be that some of the carriages firstly, and perhaps all ultimately, would leave the rails. Accidents have frequently occurred from the points being shifted before the whole train has passed over them. To prevent the possibility of contingencies of this nature, and to take out of the hands of the pointsman, all power to shift the points during the passage of a train over them, is the object of the following apparatus, illustrated in Figs. 6225 to 6227. The contrivance is the invention of Livesay

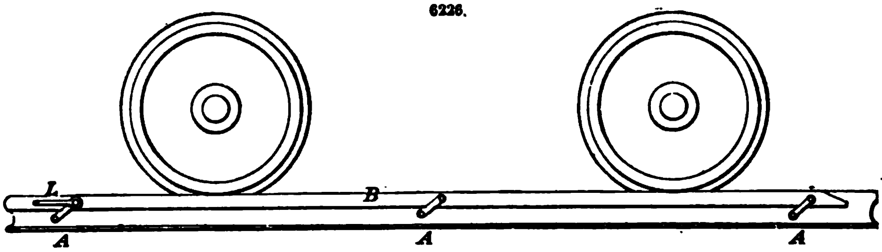
6225.



6227.



6226.

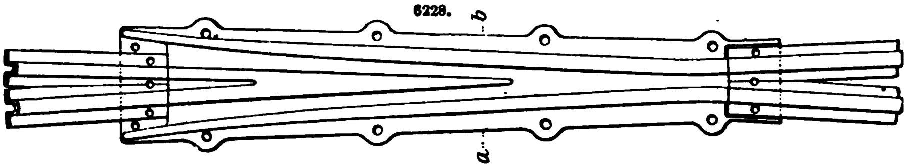


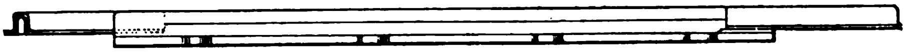
and Edwards. In Fig. 6225 is represented a plan of the arrangement, which, so far as the point X, differs in nothing from the ordinary plan of working switches. Both in the plan, Fig. 6225, and in the elevation, Fig. 6226, B is a flat bar of ½-in. wrought iron, held against the upper side of the rail and flush with its top surface. A lever L, joined to the ordinary lever R at the point X, works isochronously with it, imparting a motion to the bearings A, and causing them to make a semi-revolution every time the switch is shifted. The result of their half turn is to move the bar backwards and forwards through a longitudinal space of 4 in., raising it at the same time to a maximum height of 1 in. over the top of the rail. The train during its passage presses upon the upper edge of this bar with the same force as upon the rail, and since the points cannot be moved without at the same time moving the bar, and raising it during the motion an inch above the rail, it is manifest that their complete immovability is ensured, unless we suppose the pointsman endowed with sufficient strength to lift the bar, train and all. In Fig. 6225 the bar is shown attached to the bearer A, which is, in fact, a centre of motion, with the wheel resting upon it. The weight of the train keeps the bar down, and virtually locks the point itself, making all the arrangement self-acting. There is no necessity for the bar

being longer than what is sufficient to take two wheels, as shown in the elevation; but it should never be less than this, for if a carriage were to tilt, and the pressure, consequently, taken off a couple, there would be none upon the rail or bar throughout its length, and theoretically the points might then be shifted, although it is doubtful whether in actual practice there would be time enough for accomplishing it even wilfully. Another advantage arising from this little piece of mechanism is that it will altogether relieve the pointsman from all uncertainty respecting the passage of the train. He will have no occasion to consider whether the train has passed or not, for so soon as it has passed he may reset the points, and he will not be able to do it before, either wittingly or unwittingly. Every precaution, even to superfluity, should be taken upon our railways to ensure the impossibility of accidents.

Crossings.—These portions of the permanent way may be of cast iron, wrought iron, steel, or chilled metal, and they may be laid according to one of two principal methods. They may be laid on chairs differing only in size and slight details from those in use on the line, or they may consist of one large plate or sole-piece with the crossing rails attached to it. Figs. 6228 to 6230 represent

6228.





6230.

plan, elevation, and section of one of Ransomes and Biddell's chilled crossings, as introduced on the Great Western and other lines where the bridge rail is used. The hard wearing surface of these crossings is obtained by a mixture of irons of superior quality, which renders them very durable. They are bolted down to the sleepers, and their life, with about 300 trains running over them every day, is stated to be five years. A lighter description of this crossing is made for siding purposes, and for situations where the traffic is not so heavy. A similar example is represented in Figs. 6231 to 6233, in which the rails are fished to the crossing through the web, instead of being bolted down through the flanges, as in the case of the bridge rail. This crossing is intended for a road laid with transverse sleepers. Figs. 6234 to 6238 show the other principal type of crossing, in which the crossing is laid on chairs fixed to transverse sleepers, and not on one continuous

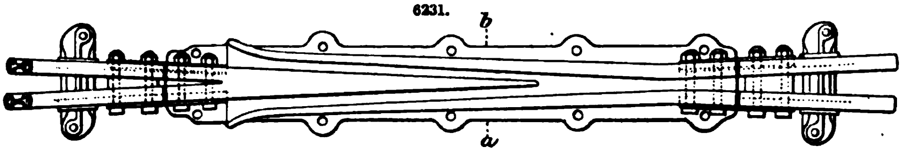
6229.

Section a.b.

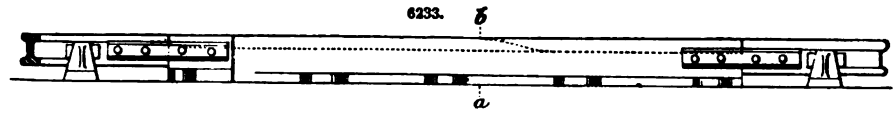
6232.

Section a.b.

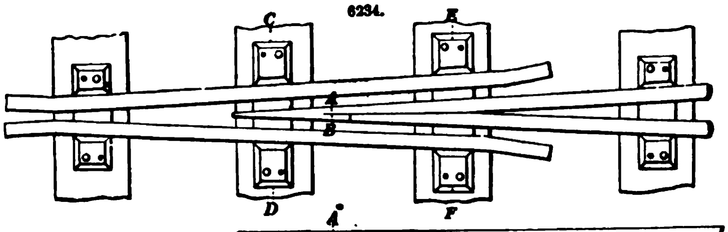
6231.



6233.



6234.

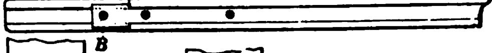


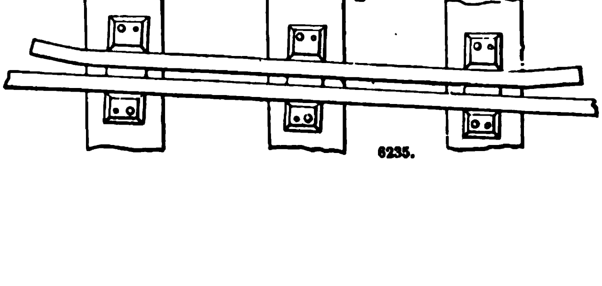
Section C.D.

6236

6237.

Section A.B.





6235.

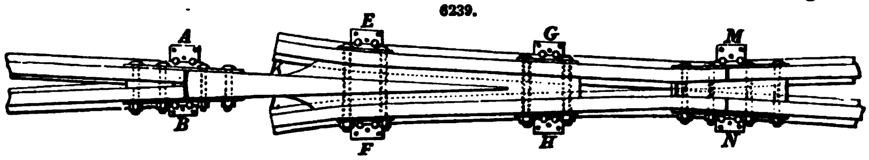
6238.

Section E.F.

sole-plate. This is the crossing which is adopted on a large scale on the London and North-Western Railway. In Fig. 6237 is shown the end of the splice rail which is shaped down to a fish-plate form, and thus a firm fastening is obtained beyond the point of the V, shown in elevation in Fig. 6235, and the two rails are securely held together. This crossing is reversible, and can be made of either steel or iron rails. The rails are held partly by the under keys and partly by the jaws of the crossing chairs, as represented in Figs. 6236, 6238.

A crossing differing somewhat in details from those already described is represented in Figs. 6239 to 6244. It is intended for the Vignoles' rail, and has a solid steel V and wings made

6239.



K.L.
6240.

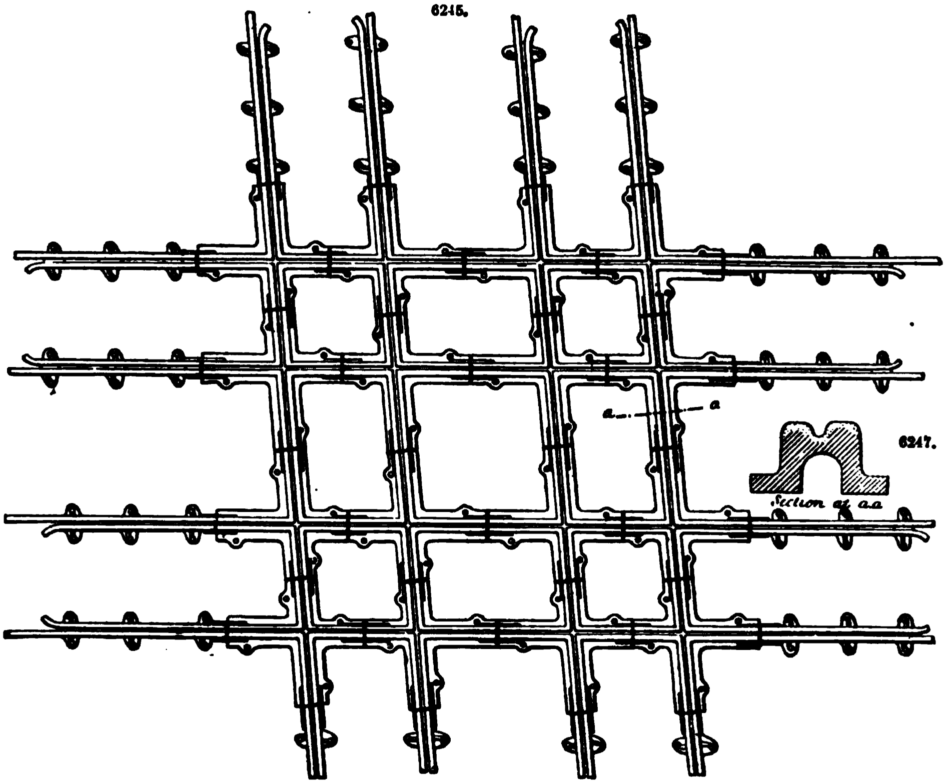
A B.
6241.

E.F.
6242.

G.H.
6243.

M.N.
6244.

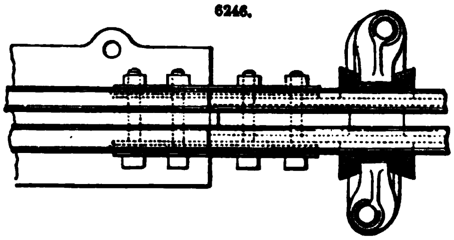
6245.



6247.

of steel rails, and possesses the advantage of considerable elasticity, being made entirely of wrought iron and steel. In the figures the chairs are shown of wrought iron, but cast-iron ones can be used if preferred. The rails are bolted to the crossing and fished as well, and the comparative shortness of the wings is a noticeable feature in the example. It is not often that one railway crosses another at right angles on the level, but there are instances in existence. To meet this contingency, one of Ransomes and Biddell's level crossings for main lines is shown in Figs. 6245 to 6247. It can be made to any angle, and certainly possesses the advantages of simplicity and cheapness. Fig. 6246 is an enlarged plan, showing the method of attaching the rails, and Fig. 6247 a section at a, a, in Fig. 6245.

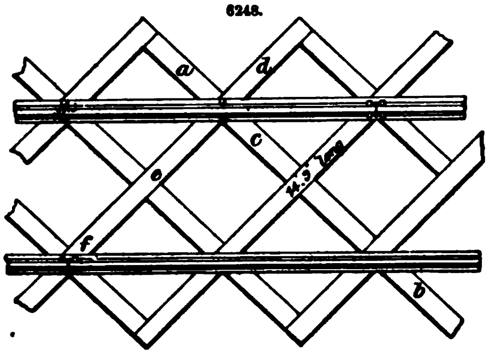
6246.



Switches made after the ordinary type are constructed of the rails forming the permanent way. In the case of bridge rails of the pattern laid down on the Great Western line, the top surface of the rail and part which fits against the stock rail are the parts bevelled off. When the rails are of the double I, or flat-footed section, the part of the upper flange not in contact with the stock rail is planed off, so as to bring it flush with the web at the point of the switch. The switch must be planed off gradually from the heel. In the examples given of switches and crossings, it will be seen that the manner in which they are connected, both with the rails of the permanent way and the sleepers, depends upon the section of the rails and the character of the road, whether longitudinal or transverse. Some sections of rails are very troublesome to fit a crossing to, and, in consequence, are rarely laid down in the vicinity of large junction stations and depôts. The life of a crossing, similar to that of a rail, depends upon the weight and frequency of the traffic running over it. It has been estimated that on the Midland Railway, or other line of average heavy and fast traffic, the life of an iron rail is, according to circumstances, from ten to sixteen years. An iron crossing, with the surface neither steeled, chilled, nor hardened by any extraneous process, would, in the same position, not last as many months. It was probably the recognition of the value of steel in crossings, which led to the gradual adoption of it in other parts of the permanent way. Crossings, being those portions of the road which suffered most severely from the effects of the traffic, were the first to benefit by the improved means taken to increase their durability and powers of resistance, which are now being extended to the whole permanent way.

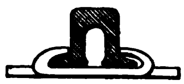
Permanent Way in the U.S.—On some of the early examples of railways in the U.S. a peculiar description of permanent way was used, called the Trellis, which deserves a brief notice. It is shown in plan and cross-section in Figs. 6248, 6249, and consists of planks or timbers *a*, *b*, *c*, about

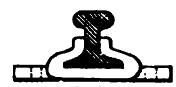
6248.



6249.

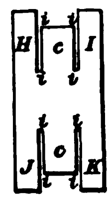
6250.





6251.

6252.



14 ft. 9 in. long, 8 in. in width, and 3 in. in thickness, laid diagonally on the centre line of the track, 56 ft. apart from centre to centre. These oblique planks are crossed by other timbers of the same dimensions, laid upon the former without notching, in the opposite direction, nearly at right angles with the first series. These planks intersect each other on the centre line of the track, underneath the two longitudinal bearers and rails. The width of the trellis foundation is 10 ft. 8 in. when the gauge is 4 ft. 8½ in. The intersection of the timbers is secured by a couple of stout wooden pins K, K, driven obliquely and nearly at right angles to each other. The longitudinal bearers L are 20 ft. in length, 8 in. wide, and 5 in. thick. The chair used is shown in Figs. 6250 to 6252. It is of slightly different form, according to the section of rail it has to receive. It consists of a flat plate of rolled iron, see Fig. 6252, from ½ in. to ¾ in. in thickness, and has four cuts *i*, *i*, *i*, *i*, made in it, and also two holes at *c* to receive the bolts for securing the chair on the trellis. The four wings I, K, and J, H, are bent up while hot, so as to embrace the base or middle of the T rail to support it, as in Fig. 6251 or as in Fig. 6250, if the bridge rail is used. The bed of the chair is let into the upper of the diagonal timbers, so that the rail may bear continuously on the timber, and the whole is secured by a pair of ¾-in. screw-bolts. The chairs made for the Baltimore and Susquehanna Railway were 5 in. wide, ½ in. thick, and weighed on the average 5·82 lbs. each. The middle part for the bolt-holes was 8 in. long and 2 in. wide, and the bent-wings J, H, I, K, which clip the rails, were each 1½ in. in width.

There have been a few modifications of the system shown in Figs. 6248 to 6252. The rail-bearers in one, instead of resting directly on the diagonal timbers, have been placed on transoms extending right across the track. In others, the diagonal timbers have been increased in number, and placed closer together, so as to form more of a cradle foundation. The quantity of timber required in a road of this description, would altogether preclude its adoption in any country but one which possessed large primeval forests. Moreover, the packing of so many sleepers, for all the diagonal timbers may be considered in that light, would be very troublesome; and it is doubtful whether, with the greatest care, a road of that kind would ever be kept in the same condition in which the lines are maintained in this country. The use of the diagonal sleepers, as ties to keep the track in gauge, is not attended with the success which might be anticipated. Diagonal ties have been tried in England and elsewhere and found wanting. Where timber is plentiful, and the ground very sloppy and bad, the trellis foundation may be temporarily used with advantage, and the larger the timbers the better. It is, however, entirely unsuited to a finished road or to the requirements of a heavy and fast traffic.

The flat tie-bar rail was originally used on the railways in the States, and was superseded by the foot rail with a broad foot or base, to be fixed to either longitudinal or transverse

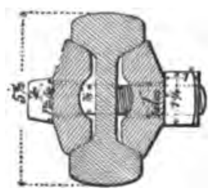
sleepers. It was bolted down to them through holes in the foot, and was generally known as the Stephenson and Vignoles' rail. This rail, fastened down with spikes, was extensively employed, although it was the source of numerous accidents. At present the single-headed rail, with a broad flange to prevent the wooden sleeper being cut into by the rail, is the favourite one in America. The joints are secured either by the ordinary fish-plates, or on the principle of the bracket-joint already described. Although steel rails are fast coming into use in the States, the above section of rail is still adhered to pretty generally. The material is changed, but the form remains the same. The weight is increased in most instances. In Canada, on the Great Western line, the single-headed rail is also used; but on the Grand Trunk the preference is given to the bridge section, which is not laid according to Brunel's system on longitudinal sleepers, but on cross sleepers. Opinions of engineers differ respecting the relative merits of these two methods of laying down the bridge section of rail.

English Permanent Way.—With a few exceptions, the transverse road and the double-headed rail may be regarded as the standard type of permanent way in England. This road is not the result of any undue preference or prejudice, but is that which experience has proved to be best adapted for the exceptionally heavy traffic, and very high speeds which prevail on the great main lines. There is scarcely a railway in the country upon which experiments have not been made with nearly every description of permanent way, which has been described in our present article, which offered any promise of success. As an example, many miles on the Great Northern Railway were laid with flat-bottom rails upon longitudinal sleepers, and after being in work for twelve years, they had to be taken up. In exactly a similar situation, the double-headed rail lasted eighteen years It must not be supposed from this that the flat-bottom rail laid on longitudinal sleepers will not make a good road. On the contrary, it makes a good and cheap road for light traffic.

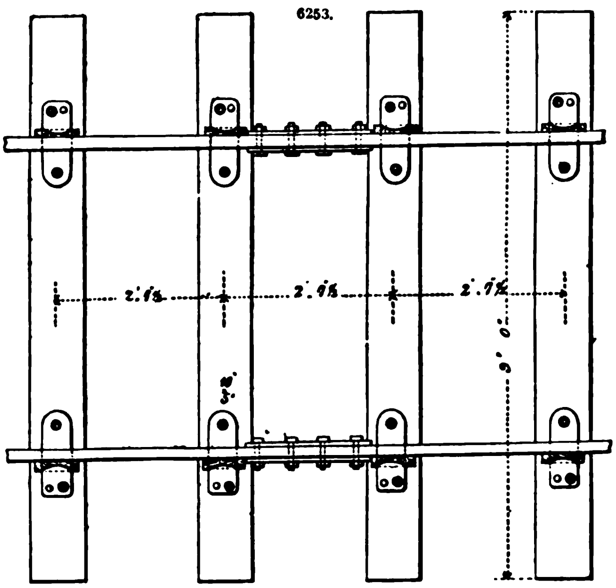
No better idea can be formed of the increase in the scantlings and weight of the various parts of the permanent way in this country, than by comparing the original road of the Great Northern line, with that in present use. Although we have selected this line for the sake of illustration, the same change has taken place in all others. The road is now, and always was, a transverse one, with a double-headed rail. The original rails weighed 72 lbs. to the yard, and were in lengths of 18 ft. There were two descriptions of chairs—joint and intermediate. The former weighed 40 lbs. each, and the latter 21 lbs., and were secured to triangular sleepers 13 in. × $6\frac{1}{2}$ in. Subsequently the joint-chairs were replaced by Adams' joint-bracket chairs, which, however, were not found to answer, and fish-plates were substituted for them universally. Now, let us compare this with the present road. While the same form of rail is retained, the weight is increased to 82 lbs. to the yard, the length to 21 ft.; and the chairs, which are only intermediate, are 35 lbs. instead of 21 lbs. They are fixed to the sleepers by a couple of spikes and a treenail. The fish-plates weigh 25 lbs. the pair. So far as the sleepers are concerned, the present are rectangular in shape, with a scantling of 10 in. × 5 in., instead of triangular, 13 in. × $6\frac{1}{2}$ in.; so that the absolute sectional area of each sleeper is diminished in the proportion of 50 to 84·5. But to counterbalance this, the present sleepers are placed much closer together, being 2 ft. $8\frac{1}{2}$ in. apart from centre to centre, and only 2 ft. apart at the joints. This is as near an approximation to a close-planked road as the spaces required between the sleepers for packing will permit of.

Permanent Way of the North London Railway.—In Figs. 6253, 6254, is one of the most modern

6254.



6253.



examples of the English system of permanent way. Fig. 6253 is a plan of the road, and Fig. 6254 a cross-section of the rail and fish-plates at the joint. The sleepers are rectangular in shape, 9 ft. long × 10 in. wide × 5 in. deep. They are creosoted, and placed at regular intervals of 2 ft. $7\frac{1}{2}$ in. apart from centre to centre, thus constituting a very closely-laid road. The chairs are of cast iron, weighing 42 lbs. each, and are secured to the sleepers by one spike 1 in. in diameter and two treenails $1\frac{1}{8}$ in. in diameter. The rails are of steel, of the double-headed section, 21 ft. in length, $5\frac{1}{2}$ in. in total height, and weighing 80 lbs. to the yard, and are fastened to the chairs by the ordinary compressed wooden keys. The joints are on the suspended principle, and are secured by

a pair of fish-plates, 2 ft. in length and four bolts ⅞ in. in diameter, two on each side of the joint, with holes 1 in. in diameter. On referring to Fig. 6254, it will be seen that the fish-plates are made with a hollow at the middle, on the side next the rail, and in fact do not in any direction press against the web of the rail, but take their bearing exclusively on the upper and lower heads, which is their proper position.

The chairs on this line are heavy in comparison with those of other similar roads, even after allowing for the increased weight of the rail. But, as a rule, chairs are lighter than they ought to be, from false ideas of economy on the part of railway companies.

In the Permanent Way of the Metropolitan District Railway, the rail is of the single-headed form, of steel, and weighs 84 lbs. to the yard. The joints are made by fish-plates, each pair of which, with its bolts, weighs 25 lbs. There are two fang-bolts to each sleeper, weighing complete 5 lbs. The sleepers are creosoted 9 ft. × 5 ft. 11 in., and weigh each 1 cwt. 17 lbs.

Continental Permanent Way.—With the exception of the single-headed rail being preferred to the double-headed, the roads on the Continent are merely imitations, and sometimes very inferior imitations, of the English. On the Prussian railways the general type of permanent way consists of a Vignoles' rail, weighing 62 lbs. to the yard, laid upon cross sleepers, to which they are spiked, the joints being secured with fish-plates. On the lines in Norway and Denmark, upon which the bridge rail is used, it weighs 60 lbs. to the yard, and the longitudinal sleepers upon which it rests are laid upon cross sleepers. The rails are connected at the joints by joint-plates. This plan was previously introduced on the Wakefield line, where the road was laid with bridge rails, weighing 75 lbs. to the yard, upon longitudinal sleepers, which were fastened to cross sleepers placed under the joints. The rails were riveted to the joint-plates with rivets ⅝ in. in diameter, a plan which experience afterwards proved to completely fail. The preference given to the single-headed rail in France, and elsewhere on the Continent, is probably due to the fact that the traffic is not of so heavy a description, either in actual weight or wear and tear, as in England. Hence a lighter and cheaper permanent way will answer all purposes. There is, however, similarly, a decided tendency to increase the weight of the rails laid down on the recently-constructed Continental railways. As the locomotives become heavier, so must the road be modified to suit them.

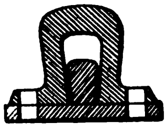
One of the most prominent permanent ways on the Continent is that laid on the Semmering incline, which deserves a brief notice.

Semmering Railway.—The permanent way laid down on the Semmering Railway, although the line is only 25¼ miles in length, is one of the most remarkable instances existing of a combination of heavy gradients, with sharp curves. The road consists of flat-based rails, weighing from 64 to 76 lbs. to the yard, resting on cross sleepers, which are spaced 3 ft. 1¼ in. apart from centre to centre. These cross sleepers are again supported by longitudinal timbers, into which they are let, and held firmly in their place by small angular brackets. The rails are 4⅜ in. in depth, and have a similar width of base, with a head 2¼ in broad and a thickness of 11/16 in for the central web. The usual length of the rails is 18 ft. 8 in. The joints are made fast by fish-plates with four screw-bolts, and underneath are placed wrought-iron chair-plates to prevent the working of the ends of the rails into the sleepers. A similar plate, but of smaller dimensions, is interposed between the base of the rail and the timber at each of the intermediate bearers. The joint-sleepers are 12¼ in. in width and 6¼ in. in thickness, and the intermediate sleepers are 9 in. × 6¼ in. wide. The wear and tear on this road is very great, but it is maintained in excellent order, which is owing, in a great measure, to the good ballasting.

The flat-footed rails, on the Continent generally, are fastened to the sleepers with dog-headed spikes, which clip round the foot of the rail, but make no holes in it, as is frequently the case on other lines upon which this rail is used. There is a small detail also peculiar to the fish-plates, which are hollowed on the side next the rail in the usual manner. But, in addition, there are a couple of small projections on the outside, at the bolt-hole, which serve to hold the head of the bolt firmly in its place. The chief reason why a lighter rail can be used on the lines abroad, is not so much on account of any difference in the actual weight of the traffic running over them, but because the speed is very much less. A common load upon one driving wheel is about 5¼ tons.

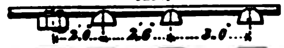
Irish Permanent Way.—The description of permanent way, adopted on the majority of the Irish lines, is due to John Macneil. The rail is of the bridge form, shown in Fig. 6255, and weighs 83 lbs. to the yard run, and presents some slight difference in its shape from others of the same type, such as those used on the Great Western Railway. It is 3¾ in. in height, and 5⅝ in. broad at the base. The thickness of the head is 1 in., and the space between the inner edges at the bottom is also 1 in. Fig. 6255 shows that the exterior sides are closer together at the bottom than at the top, thus forming a kind of dovetail. This particular shape cannot be imparted to the rail at the time it is rolled, but is given to it by passing the rail on edge between a pair of jaws, by which it is compressed into that form as in Fig. 6256. Contrary to the general practice, the rail is laid on transverse sleepers, shown in plan and elevation in Figs. 6257, 6258. At the joints, the sleepers

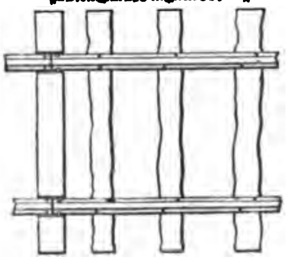
6255.



6256.

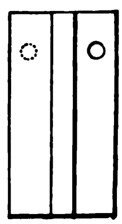
6258.





6257.

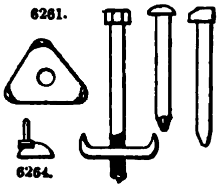
6259.



are half balks of red pine, 12 in. × 6 in., but the intermediate sleepers are either of larch or Memel, and measure at the smallest end not less than 8 in. × 4 in. The joints are made by chairs, shown in Fig. 6259, of rolled iron, 12 in. long by 6 in. wide and $\frac{3}{8}$ in. in thickness, and having in the central part a ridge 1 in. in thickness and $1\frac{3}{4}$ in. in height, rolled as accurately as possible to fit the hollow of the rail. In laying the joints, each end of the rails is passed over the ridge, and a good blow or two with the hammer makes all secure. To attach the rail and chair to the joint-sleeper, at one end of each rail a bolt $\frac{3}{4}$ in. in diameter passes through each flange of the rail, and also right through the chair and sleeper. It is then fastened by a nut of a triangular shape of wrought iron $\frac{3}{8}$ in. in thickness. The ends of this nut are turned up, as in Figs. 6260, 6261, so that when the bolt is screwed up from above, they are forced into the timber and hold immovably. In order to allow for expansion, one end of each rail is not rigidly fixed to the chair, but is fixed in such a manner as will allow it to slide backwards and forwards on the chair and sleeper. It is prevented from moving in a vertical and lateral direction by a clip-bolt, shown in Fig. 6260, which is driven on the outer edge of the chair and flange of the rail. Ordinary spikes, roughly pointed, see Figs. 6262, 6263, are used for attaching the rails to the intermediate sleepers.

6260. 6263. 6262.

6261.



6264.

In addition to the spikes a bed is cut in the sleepers to fit the rail. The chairs are placed only at the joints. In Fig. 6264 is shown the position of the cutter when cutting the bed in the sleepers. Its spindle is placed at a slight angle with the vertical in order to give the proper inclination to the bed to correspond to the conical tire of the wheel. The intervals between the sleepers, which are not equal, are shown in Fig. 6257. The advantages claimed for this description of road are that it cannot get out of gauge; that the expense is saved of renewing and tightening up keys, and that it is a very easily packed road. The total weight of the wrought-iron fastenings to each rail, 15 ft. in length, is 41 lbs., of which the joint-chair weighs 16 lbs. The fastenings on this road, like all others, are liable to be loosened by vibration. The pins and triangular-spiked plates were used on the Great Western Railway, but it was found that the coach screws used for fastening down the rails would not hold by reason of losing their thread. The principle of the bridge rail laid upon transverse sleepers, has been pronounced by many engineers to be unsound in both theory and practice. A single line of rails, weighing 80 lbs to the yard, of that description of permanent way was laid on the Brighton and Chichester Railway, but subsequently abandoned for another in which double I rails weighing 75 lbs. a yard, and cast-iron chairs of 24 lbs. and 28 lbs., were employed.

TABLE III.—SHOWING DETAILS OF THE DIFFERENT PERMANENT WAYS IN USE UPON THE PRINCIPAL RAILWAYS IN ENGLAND AND ABROAD.

Name of Railway.	Description of Road.	Sleepers.	Chairs.	Joints.	Section of Rail.	Weight of Rail in lbs. a yard.	Weight of Chairs in lbs.
Great Western	longitudinal	timber	none	chairs	bridge	75	..
London and North-Western	transverse	"	cast iron	fish-plates	double I	80	..
Midland	..	"	..	..	..	..	..
Great Northern	"	"	"	"	"	82	35
South-Western	"	"	"	"	"	75	..
North London	"	"	"	"	"	80	42
Metropolitan District.. ..	..	"	none	..	single-headed	..	..
London, Chatham, and Dover	..	"	..	..	..	..	..
South-Eastern	"	"	cast iron	"	double I	75	28–30
London, Brighton, and South Coast	..	"	..	..	..	..	..
Great Eastern	..	"	..	..	..	..	..
Bombay and Baroda	"	"	"	"	"	65	..
Madras	"	"	"	"	"	82	21
Great Indian Peninsular ..	"	"	"	"	"	65–84	..
Scinde and Punjaub	"	"	"	"	"	66–84	22
East Indian	"	"	"	"	"	73–84	22–25
Egyptian	..	Greaves' sleepers, 80 lbs. each.	..	..	..	..	..
Norwegian	"	timber	none	"	Vignoles	37–40	..
Rio de Janeiro	..	Greaves' sleepers, 80 lbs. each.	..	..	double I	65	..
Lisbon and Santarem ..	"	timber	cast iron	chairs	single-headed	60	20–30
Santiago and Valparaiso ..	"	"	none	..	"	84	..
Festiniog	"	"	cast iron	"	"	30	10–13
San Francisco	"	"	"	fish-plates	double-headed	72–80	24–39
Continental Lines	"	"	none	"	single-headed	64–76	none
Australian Lines	"	"	..	..	..	..	..
American, U.S.	"	"	..	..	..	..	..
Canadian Lines	"	"	..	..	..	..	..
Irish Lines	"	"	wrought iron	chairs	bridge	83	..
Mauritius	"	"	..	..	..	..	..

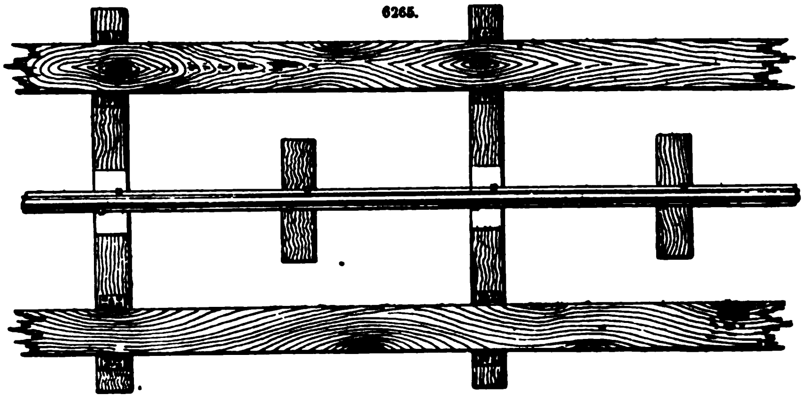
It is worth noting that a rail which dispenses with cast-iron chairs, and is fastened directly to the sleepers, possesses some advantages which deserve attention. But the same, and probably, superior advantages can be obtained by the employment of the single-headed, flat-footed rail, such

as is used on the Continent. Of all the forms of rails, the bridge section is that which is the most seldom laid down on new railways, and at no distant date will probably be abandoned. Other sections are used in Ireland, as described under the section Rails in the present article, but the bridge is the distinguishing type of rail laid down. As a proof of the great increase in the weight of rails, it may be mentioned that the permanent way of the Dublin and Kingstown line was originally laid with rails weighing 42 lbs. to the yard, and fixed in the primitive fashion to square blocks of granite.

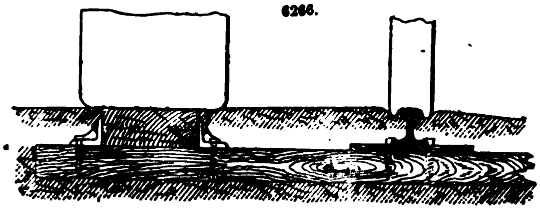
In Table III. are given the principal features of the more important permanent ways in use at home and abroad. It is not to be understood that other descriptions of roads are not occasionally employed, but those given in the Table represent the most general types.

Larmenjat System of Permanent Way.—This description of road, which is of a peculiar and novel construction, has been very recently successfully introduced in Portugal. In general principle, it consists of longitudinal planking for the driving wheels of the engine, which are broad, and have no flanges to run on, with one rail laid in the centre of the track to keep the engine on the road. A leading and trailing central wheel with double flanges on the engine, grip the rail. In Fig. 6265

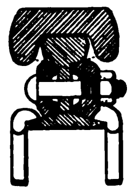
6265.



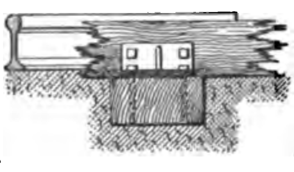
6266.



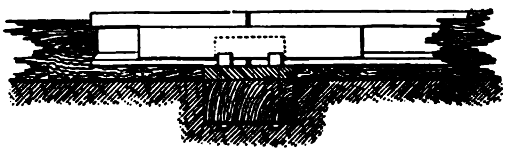
6272.



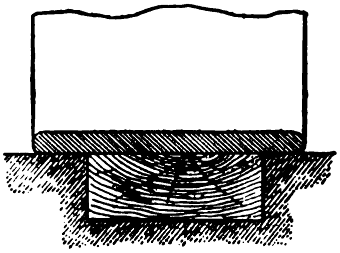
6267.



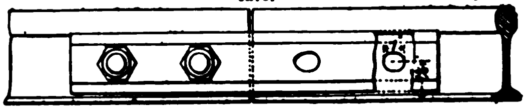
6268.

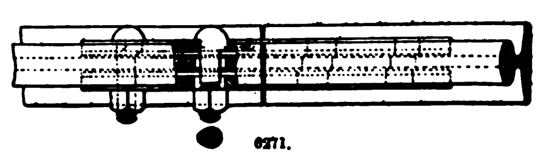


6269.



6270.





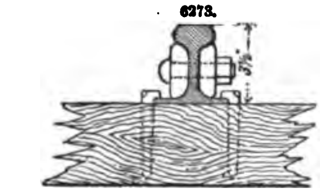
6271.

a plan of the way is shown. The longitudinal planks, or wooden rails, are laid apart at intervals of 6 ft. upon cross sleepers; the central rail, which is of iron, is supported on these cross sleepers, and also upon short intermediate ones, placed half-way between the longer ones, so as to

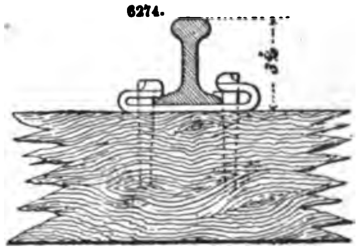
afford a bearing of 8 ft., measured from centre to centre. The gauge from the centres of the longitudinal planks is 4 ft. 2 in. The planks are 9 in. × 4½ in., and the cross sleepers 6 in. × 3 in. × 6 ft. in length from out to out. A cross-section of half the road is shown in Fig. 6266, in which is seen the driving or traction wheel of the engine, and the central wheel. The longitudinal planks are attached to the cross sleepers by small angle-iron brackets and four wood screws, as in Fig. 6267. The manner of securing the central rail to the cross sleepers is shown in Fig. 6266. The top of the rail is maintained nearly half an inch above the longitudinal planks, by a packing strap, 12 in. × 6 in. × ⅜ in., shown in Figs. 6267, 6268, and is double-spiked on sharp curves. Fig. 6269 represents a section of the tire of the driving wheel, which is 1 ft. 2 in. in breadth, and 1¼ in. in thickness, and projects over the edges of the longitudinal planks. The object of this is to prevent the wheel being affected by any trifling sinking of the planks. An elevation of the rail joint is shown in Fig. 6270 and a section in Fig. 6271, which explain themselves. A cross-section of the rail at the joint is given in Fig. 6272, showing the fish-plates, and the mode of securing the rails to the sleeper by dog-headed spikes. All the bolts in the rails have Whitworth standard threads, and the nuts do not in any case exceed ¾ in. over small diameter.

Light Railways.—As a good type of light railways, or lines intended to act as feeders to main routes, and also as well adapted for countries which have not committed themselves to any standard gauge, the Norwegian lines may be mentioned. The permanent way upon these lines consists of flat-bottomed rails weighing from 37 lbs. to 40 lbs. to the yard, fished at every 21 ft. with plates 11 in. in length, and secured by dog-spikes only to transverse sleepers 2 ft. 6 in. apart from centre to centre. No fang-bolts or joint-plates are employed. The sleepers, which are of pine, are 6 ft. 6 in. long × 9 in. × 4½ in. in section, uncreosoted and half round, laid with the round side up, and adzed to increase the bearing of the rail to 5 in. An inward cant of 1 in 20 is given to the rail. In Fig. 6273 is represented a cross-section at the joint of the rail and fastening used on the light railway from Arconum to Conjeveran in the Madras Presidency. The rail weighs 35½ lbs. to the yard. It is properly fished and secured by dog-spikes to transverse teak sleepers spaced 2 ft. 6 in. apart from centre to centre.

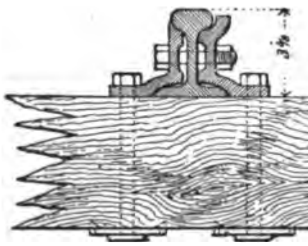
6273.



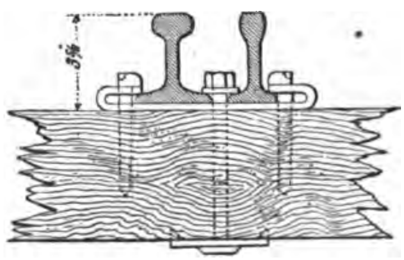
6274.



6275.



6276.

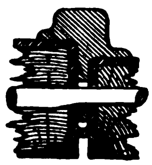


The Queensland railways are good examples of modern light railways. They have a gauge of 3 ft. 6 in., and the permanent way adopted is shown in Figs. 6274 to 6276. Fig. 6274 shows the section at the joint; Fig. 6275, the chair for curves of the ordinary radii, and the mode of fastening; and Fig. 6276, the chair and guard rail adopted for curves of the small radius of 5 chains. The road consists of flat-bottomed rails, weighing 40 lbs. to the yard, of a general length of 20 ft. The rails are laid vertically, fished with Adams' bracket-plates, and secured at the joints by fang-bolts, and elsewhere by dog-spikes to transverse rectangular sleepers, laid 2 ft. 6 in. apart from centre to centre. In India, and countries which are destitute at present of all railway accommodation, there is a large field for lines of a lighter description than those so common with us. While there is room for discussion, respecting the advisability of adopting light railways in countries which are already committed to a standard gauge, there cannot be the slightest doubt with respect to the benefits which will ensue from their introduction in our colonies and countries whose internal resources are hitherto undeveloped.

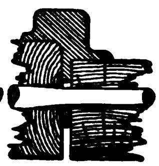
Griffin's Permanent Way.—The inventor of this system claims for it many advantages. He states that the Griffin rail, as represented in Figs. 6277, 6278, is designed to economize metal, and in proportion to its wearing surface, to afford such vertical strength as will ensure by the distribution of the strains upon it ever a large surface the least possible injury to its timber support. Neither vertical stiffness nor weight is sacrificed in this form of rail, which, with its deep solid head, without overhanging, and its thin girder web, is so firmly held in its enclosed position by its fastening, that any tendency to turn or buckle is prevented. Not considering the additional

strength given to the rail by its deep web, the head alone is wider and stronger than that of the Great Western Railway; because, whilst the great weights passing over the latter tend to open it, and press the fastenings out of place, the former is solid, and without that tendency.

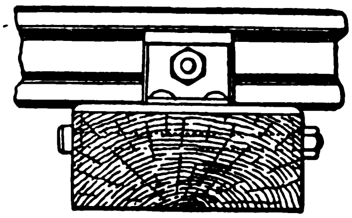
6277.



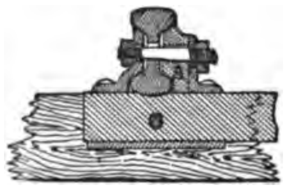
6278.



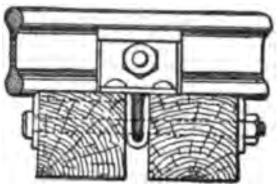
6279.



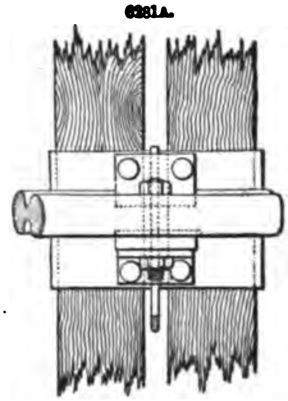
6280.



6281.

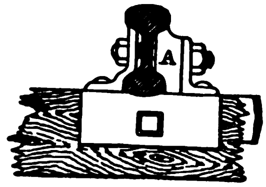


6281A.

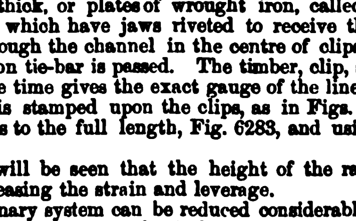


Plan.

6282.



6283.



With the ordinary double-headed or Vignoles' rail, Griffin takes two pieces of timber 2 or 3 ft. long, from 5 to 12 in. wide, and from 5 to 6 in. thick, or plates of wrought iron, called clips, stamped into the forms shown in Figs. 6279 to 6283, which have jaws riveted to receive the rail, and they embrace one or two pieces of timber. Through the channel in the centre of clips, Figs. 6281, 6283, and exactly to fit it, a strong wrought-iron tie-bar is passed. The timber, clip, and tie-bar are immovably fixed by a bolt, which at the same time gives the exact gauge of the line.

The rail is tightened down upon the bed, which is stamped upon the clips, as in Figs. 6284 to 6286, by an eccentric bolt. By lengthening the jaws to the full length, Fig. 6283, and using two instead of one bolt, a thorough joint is secured.

This method is shown in plan in Fig. 6287. It will be seen that the height of the rail from the base of the sleeper is here reduced by 3 in., decreasing the strain and leverage.

The weight of rail used compared with the ordinary system can be reduced considerably, as it has more direct support, and the short bearings and comparatively elastic bed prevent cutting and distress to the fibre of the iron.

The sleepers are independent of climatic influence, more direct bearing is obtained; and so long as it is strong, timber of almost any quality, shape, or size, may be used, as in Figs. 6288, 6289. By withdrawing a bolt any sleeper can be replaced in a few moments.

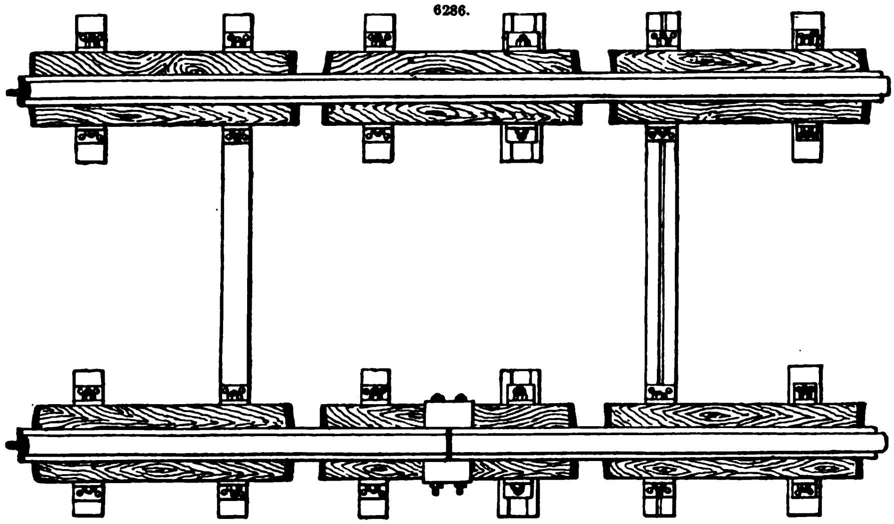
The clips, Figs. 6279 to 6283, are of a common description of rolled iron, and are easily made. They cover more surface than a chair, and oblige the sleepers to bed fairly under some of their loads.

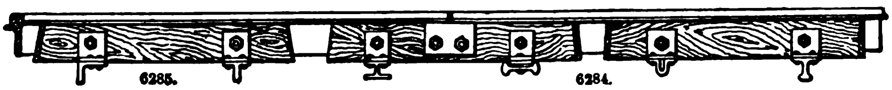
The fastenings are of a strong and durable description, and have little strain to support, as this is sustained by the sleeper.

The filling-pieces may be of compressed wood or of iron, Figs. 6284 to 6286, and are made to fit without driving. The wrought-iron jaws, when screwed together, by the eccentric bolts passing

through the jaws, rail, and filling-pieces, hold all together as a solid, and give the amount of compression required.

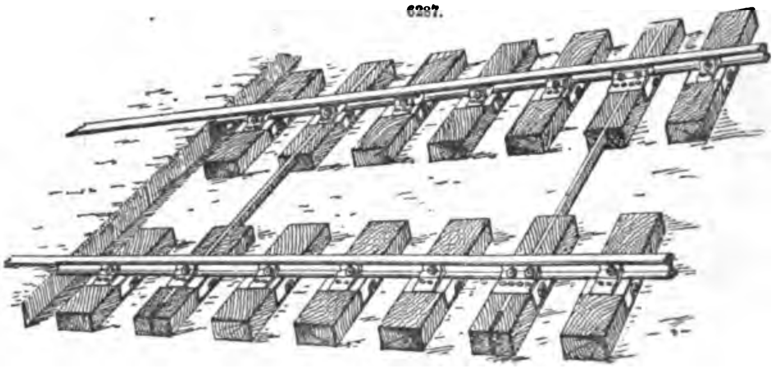
6286.



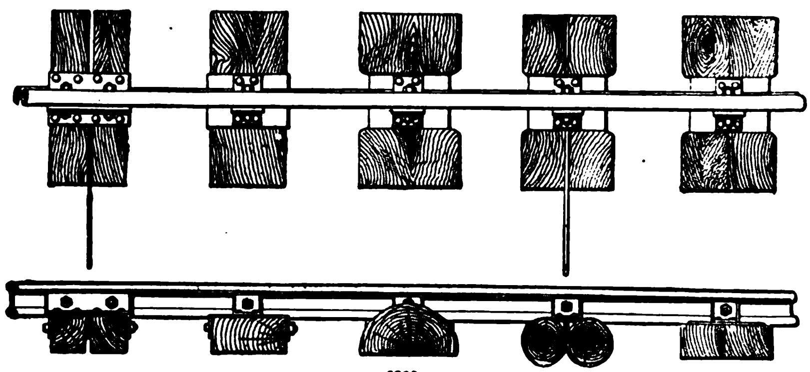


6285. 6284.

6287.



6288.



6289.

The gauge is always kept true by the tie-bar, more especially at the joints, which are as strong as any other portion of the road. The full-sized clips average but 16 lbs., and fish-plates are dispensed with altogether.

The sleepers are a combination of the longitudinal and transverse systems, and whilst the advantages of a longitudinal sleeper are secured, those in the transverse system are also preserved.

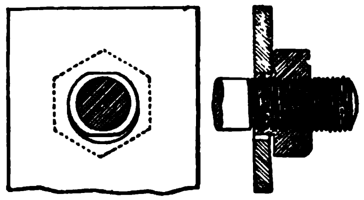
A class of timber may be used, which is now useless, for permanent way purposes, and oak, or other hard woods, suitable for making the best and most durable roads, can be bought of such small sizes as are necessary.

Sawing and boring the timber is all the work necessary to convert it into a sleeper; and the sizes required are so small as to allow of it being readily procurable in many situations where ordinary sleepers cannot be obtained.

The fastenings are either eccentric or concentric bolts, Figs. 6277, 6278, the screwing forward of which tighten the rails upon the sleepers. They are comparatively very large in size, of one uniform kind, and though they can be removed in a few minutes, firmly secure the rails and sleepers together.

The nut of each fastening, Figs. 6290, 6291, locks itself, and cannot work loose. This is effected by having the collars upon the nuts, which pass through the jaws, flattened very slightly on two opposite sides, and the hole through the angle-iron, or jaws, punched with a corresponding flatness at the top. When the rail is tightened down upon the sleeper, and has a strong tendency to rise, half a turn of the nut brings the two flattened surfaces together.

6290. 6291.



The tie, or gauge-bars, are of any desired section of T girder, angle, or channel iron, or old worn-out rails, adapted as in the plan on side view, Figs. 6284 to 6286. Any desired strength can be given, and they form a part of the permanent foundation, which is all designed so that they can be placed as near or as far apart as found necessary. The same jaws and bolts being used upon them as upon other parts of the foundation, not only admit of this, but at the same time make them available for holding down, tightening the rail upon the sleeper, and adjusting the exact gauge of the line.

Some sections are better adapted for this purpose than others, but as a general principle the heavier sections are the most durable.

Any section of T iron is applicable for foundation and timber support; but T iron being twice the cost of worn-out rails, a more substantial line can be made with the latter, for the same cost as shown in Fig. 6284 to 6286.

There is evidently no saving in simplicity in this road, as the component parts are very numerous; and it is questionable whether the saving in the length of the sleepers will prove of the importance anticipated.

Concluding Remarks.—The question will naturally present itself, what is the limit at which the increase of weight in the locomotive and general traffic, and consequently the corresponding increase in the weight of rails, and details of the permanent way, will stop? It is clear that it must stop somewhere. The probability is that the maximum weight of the rails will never much exceed 85 lbs., even should the weight of the engines be still further augmented. The result of any further increase in this particular would be, not to put more weight upon any one or any pair of wheels, but to distribute it more uniformly, so that it would not tell so severely upon the road. It is the terrific pounding of driving wheels of large diameter, running at very high speeds, which is so destructive to the rails and permanent way generally. The manner in which the weight is distributed makes the real distinction between a heavy and a comparatively light traffic, and not the actual amount of the weight itself. This is one reason which causes the permanent way on the Continent to be of a lighter description than in this country. It is not that the loads are not so heavy as ours, but the weight is more uniformly distributed, and, in addition, they are not conveyed at so high a speed, which is an equally, if not more important consideration. Looking at the question in all its bearings, and judging from the past, we are strongly of opinion that the future permanent way in this country will, with some few exceptions, consist of the transverse-sleeper road, with sleepers laid as closely together as the spaces necessary for packing will allow. These will carry a double-headed steel rail weighing not less than 82 lbs. to the yard, fixed in cast-iron chairs, with compressed wooden keys, and fish-jointed. It will be time enough to turn attention to a road altogether of iron, when it is no longer possible to obtain timber for the sleepers, if that day should ever arrive.

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PERSIAN WHEEL. Fr., *Roue persanne*; Ger., *Schöpfrad*; Ital., *Ruota persiana*; Span., *Noria*.

See Mechanical Movements, Fig. 5791.

PET COCK. Fr., *Robinet de cylindre*; Ger., *Wasserablasshahn*; Ital., *Chiavetta di prova*; Span., *Llave de comprobacion*.

A pet cock is a cock placed in the delivery-pipe of a pump to show if it is working.

PICK. Fr., *Pic;* Ger., *Keilhaue;* Ital., *Piccone;* Span., *Pico.*

A pick is an iron tool into which is inserted a wood handle; it is used for loosening and breaking-up hard earth, ground, stones, and so on.

See Hand-Tools.

PICKER. Fr., *Epinceur;* Ger., *Nopper;* Ital., *Diavolo;* Span., *Escardador.*

Any machine for picking fibrous materials to pieces is termed, in mechanics, a picker, as a wool-picker, a rag-picker.

PIERS. Fr., *Jetée, Môle;* Ger., *Hafendamm, Hoft;* Ital., *Calata, Molo;* Span., *Muelles.*

Piers are masses of stonework or moles projecting into the sea, for breaking the force of the waves and making a safe harbour. Also, any projecting wharf or landing-place is termed a pier. Architecturally, piers are masses of solid stonework for supporting an arch, or the timbers of a bridge or other building.

See Construction. Docks. Harbours. Piles. Retaining Walls.

PILE-DRIVER. Fr., *Sonnette;* Ger., *Ramme, Ramm-maschine;* Ital., *Bertacapra;* Span., *Machina.*

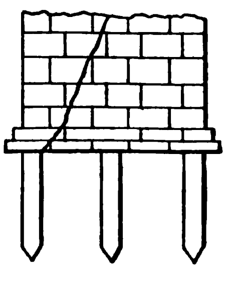
Piles and Pile-driving.—The nature of the ground, the thickness of the various layers or small strata, and the depth of the firm ground ultimately arrived at, are the points to which attention should principally be directed in getting in pile foundations. There are two methods of piling generally used. The one, and the more ancient, consists in simply forcing down timber piles by repeated blows of an iron block called a monkey; the other, which is but of recent origin, consists in screwing iron piles into the earth by imparting a rotary motion to them by means of levers, which may be arranged in a variety of ways. Both of these methods are valuable and reliable under certain circumstances, but there are objections to their universal employment which we shall examine.

The object to be attained, in driving down a series or row of piles, upon which to erect a pier or abutment, is to replace a naturally loose, movable foundation by an artificial one, based upon a firm support, and upon which the superstructure will rest. It is therefore of the greatest importance that this artificial foundation should be immovably fixed, and that every individual member of it—that is, every separate pile—should penetrate into the solid ground. This last condition, which is the most essential, is one that is frequently not fulfilled. In driving a pile, for example, through soft muddy earth, it goes down at first with considerable velocity, the effect of each blow being distinctly visible. After a short time the rapidity of descent diminishes more and more, until apparently no effect follows the succeeding blows, and at last the pile refuses to go down any farther. At this point it is commonly supposed that the pile is driven far enough, and that solid ground is reached. Often this assumption is false, and serious results have happened from an ignorance of the error. Although the further descent of the pile may be arrested, it does not necessarily follow that a solid foundation is reached; for when a pile is of great length, the lateral pressure of the surrounding strata in the vicinity of the point is very great. This pressure grips the point and sides of the pile like a vice, and by imparting an apparent immovability to it, produces the same effect as if it had really reached an impenetrable stratum. From Fig. 6292 it is clear the pile might be wedged up and retained immovable, although there was nothing beneath it, the surrounding lateral pressure having once reached a certain amount being sufficient to keep it fixed. The same cause gives rise to the vibrations, which all have observed in piles when superintending their driving; for the earth becoming more and more compressed, at last exerts its elastic force, and after yielding temporarily to the force of the blow recovers itself, and by its pressure against the pile imparts a vibratory and tremulous motion to it.

6292.

Sufficient attention has never been bestowed upon one feature belonging to founding on piles which have been got down by driving, which relates to the different manner in which the weight is brought upon the piles firstly and lastly. The weight which drives them down is sudden, rapid, violent, and concussive; that which they have permanently to withstand is gradual, slow, gently applied, and uniformly distributed. Now, it is a well-recognized mechanical fact that a weight applied continuously and unremittingly, will ultimately produce an effect which ten times the weight applied in the manner described will fail to accomplish. Let us apply this principle to the pile in the above situation. After the superstructure has been finished, which, so far as mere weight is concerned, may be twenty times that of the monkey employed in driving the pile, the continuous nature of its action begins to make itself felt; the lateral pressure commences to yield little by little, and the piles, together with their superincumbent load, sink slowly but appreciably. These remarks apply with still greater force to a number of piles driven close to one another; as, in consequence of the earth becoming more dense and compact as every succeeding pile is got down, it opposes a much greater resistance to penetration, and there is never the same depth attained with the last piles as with those first driven.

6293.



The danger attending an irregularity in the depth to which a row of piles is driven, is that when a settlement takes place. It is also irregular, and is sure to occasion unsightly cracks in the masonry, if it does nothing worse. Fig. 6293 represents a portion of a pier founded upon piles, the left-hand corner one of which has sunk, and the result is the crack shown, which continues up throughout the entire height of the pier. If this crack is of such a size as to endanger the safety of the pier, the only remedy is to pull it down; but if it is very slight, what is technically termed

a thread, fresh pointing will obliterate the mere appearance of it upon the face of the work. It is not a settlement, provided it is not an absolute sinking, that necessarily exposes a structure to danger of falling, but the irregularity of the settlement that works the evil. In an arch bridge, for example, if both abutments were to sink perfectly uniformly and regularly, the result would be simply a lowering of the whole bridge; but if one were to settle and not the other, the arch would be in danger of breaking. It is partly for this reason, combined, however, with other considerations equally important, that where the foundations of a proposed bridge are known to be bad, it is usually designed, in railway work at least, as a girder and not an arch, since the partial settlement of one abutment would produce no other effect upon the stability of the bridge than the lowering of one end of the girders, a circumstance of little consequence within certain limits. It will probably be remarked that the depth at which a real solid stratum is to be obtained, might easily be ascertained by boring, previously to commencing the pile-driving. To a certain extent this remark is correct; but not unfrequently the borings which would reveal the true nature of the ground, are either altogether omitted, or conducted in a manner so careless and slovenly, that the results elicited from them are little better than worthless for all practical purposes. On the other hand, it must be admitted that it is very difficult to estimate what the exact character of the ground may be, with respect to its solidity or bearing power, from even the most accurate and most carefully-conducted borings, and it must, moreover, never be forgotten that all borings are peculiarly local, and that ground which appears hard and consolidated at one spot, might, and does, present a totally opposite character at a distance of only a few feet. A convincing proof of the error of assuming that a solid foundation was obtained at a certain depth, was afforded by the total failure of several bridges and viaducts on the Ligne du Midi, in France. These structures were founded upon piles in a soft substratum, driven down to a depth of 40 ft., where it was confidently believed a hard bottom was arrived at. After the failure took place borings were made, and it was discovered that solid ground was not reached until a depth of nearly 80 ft. had been sounded, thus fully demonstrating the reason of the sinking of the various works along the line. To penetrate to any depth by driving into pure sand is a simple impossibility; one might as well attempt to drive a pile into rock. In fine gravel the obstacles are very nearly similar in character and amount; and, as a rule, the difficulty of penetrating gravel by direct impact, may be said to vary inversely as the size of the particles. When the principle of impact fails, we can, under certain considerations, have recourse to that of rotation, and the system of founding upon screw piles has met with much success, notably so in getting in foundations under water.

Timber Piles.—The timber most employed for piles in this country is elm, fir, and beech. In cases where hard driving is necessary elm is to be preferred, as it is not nearly so liable to split in being driven as beech or fir. Those who have had experience in pile-driving are well aware of the cost and trouble incurred in drawing piles that have been split in driving. When timber is exposed to the alternations of wet and dry weather it does not last for any great length of time, but if kept constantly under water, and not exposed to the attack of the *Teredo navalis*, or pile-worm, it will remain sound for a very considerable period. Beech and elm are much better when used in a green state if required to be placed under water permanently. Some of the fir guide-piles, and portions of the caissons of the Westminster old bridge were as sound when drawn out as when placed there, about 120 years before. In the selection of timber for piles, care should be taken to procure them as straight and as free from knots as possible, as they are then much less liable to split, and better for driving in all respects. It is also preferable to use whole timbers than portions of large balks. When the scantling of the timber is too large, it is better to cut the piles out of the heart of the wood, as they are then less likely to split in driving.

Bearing and Sheet Piles.—Bearing piles are those which are used either for directly supporting a superincumbent pressure, or as an assistance to sheet piles when the object is to retain or hold up a mass of earth or other material. They should always be whole timbers, not less than 12 in. square, and are usually shod with a cast or wrought iron shoe. They should be in one length where possible. Timber is not so readily procurable in long balks as formerly. Sheeting piles are generally half balks, and are driven close together so as to constitute a continuous timber wall. They derive their resistance partly from the ground into which they penetrate, and partly from the main piles to which they are connected by the waling-pieces. These latter are pieces of timber, usually whole balks, bolted or spiked to the main or gauge piles, and between them the sheet piles are driven. A good example of sheet piling is when they form the sides of a caisson. Briefly, the distinction between main or bearing and sheet piles is that the former are subject to vertical pressure, and the latter are not. Sheet piles are sometimes whole timbers where the retaining power is required to be very great.

When the object is simply to consolidate the ground, what are termed sheet piles are driven in considerable numbers and very close together. This plan is, however, seldom adopted now by engineers, who prefer to use concrete. Fender piles are employed, as their name signifies, to protect the face of any permanent structure from injury by blows or concussions. They are of whole timbers, and are driven along the face of river walls and embankments at intervals of about 10 ft. They need not go farther into the ground than what is sufficient to give them a good hold. Sometimes they are not driven, but a hole is excavated for them, and the earth subsequently well rammed in round them. If the face of the wall is battered or curved, the inside of the pile must be trimmed to make a good and close fit. A cluster of fender piles braced and strutted together constitutes a *dolphin*, which is triangular in shape, and is always placed in front of any temporary work in progress in a navigable river.

Excavating for Piles.—In order to facilitate the driving of piles, the ground is frequently excavated to some depth, and also dredged out as well along the line of pitching. At the construction of the dam for the Thames Embankment on the north shore, with the view of saving time, the ground was not dredged before the piles were driven, and the driving was in consequence a slow and difficult operation. In many cases it was all but impossible to force the piles down, and about

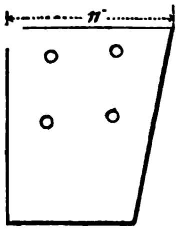
one-sixth of the whole number pitched, having, in the process of driving, appeared to have failed, were drawn, and other piles were substituted. Whenever a pile was observed to show symptoms of failure in driving, it was drawn; and in this dam ninety-five piles were so removed and replaced. Generally, the piles when drawn were found to have cast their shoes, and their points were bruised into a mass of tangled shreds. The failure usually occurred whilst the point of the pile was passing through a bed of close, compact sand, containing fragments of shells, which rested on coarse open gravel. Beneath the gravel, and resting on the clay, was a layer of septaria, which presented a serious obstruction to the passage of the piles. Once through this stratum and into the clay, the driving became comparatively easy.

Notwithstanding the precautions which were taken to draw and replace injured piles, it was afterwards ascertained, when the foundations were excavated inside this dam, that about one-fourth of the piles which remained were bruised and broken, and had not penetrated the clay. The piles were of whole timbers, in lengths of from 40 ft. to 48 ft., and from 12 in. to 14 in. square. They were shod with cast-iron shoes, weighing 70 lbs. each, and were driven, or were intended to be driven, 4 ft. into the clay. Cast-iron shoes were used in preference to those of wrought iron, as giving, at an equal cost, a much larger base for the timber. Where the driving was very difficult, shoes having cast-iron bases and wrought-iron straps were employed.

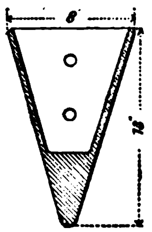
Heading and Shoeing Piles.—To ensure the quick and proper driving of a pile, great attention ought to be paid to heading and shoeing, which is a very important point. If the shoe gets twisted the pile cannot be driven accurately, and should it come off, the withdrawal of the pile frequently becomes necessary. The best scrap iron should be used for the hoops with which the piles are headed, and also for the shoes. The weight of the hoops used for the bearing piles of London Bridge was 30 lbs., and that of the shoes 35 lbs. These piles were, on an average, not less than 20 ft. long, and 12 in. diameter in the middle. One of the best kinds of shoe was that used for the bearing piles at Westminster new bridge. It was a combination of wrought and cast iron, the point being cast and fixed on with wrought-iron straps. The weight of the hoop used was 38 lbs., that of the shoe 60 lbs., including rivets, jagged spikes, and straps. The cast-iron point by itself weighed 28 lbs. The piles averaged upwards of 30 ft. in length, and 14 in. × 14 in. scantling.

In Figs. 6294 to 6299 are shown the shoes used for the piles in the dam already mentioned.

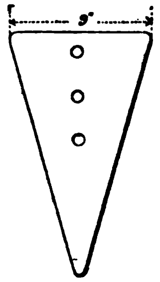
6294.



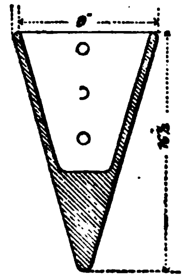
6295.



6296.

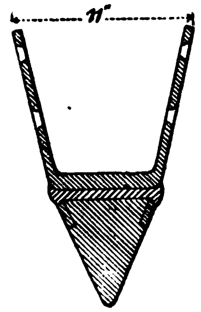


6297.

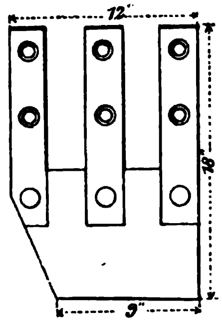


Those for the sheeting piles are wholly of cast iron, and all represented in elevation and section in Figs. 6294, 6295. Those for the gauge-piles are similarly shown in Figs. 6296, 6297, and are also wholly of cast iron. The shoes shown in elevation and section in Figs. 6298, 6299, are partly of cast and partly of wrought iron. The bosses are of cast iron and the straps of wrought iron. In certain soils cast-iron shoes will answer extremely well; but in others, those of wrought iron must be employed In fact, if there is any great difficulty to be encountered in driving, it is preferable to adopt wrought-iron shoes. At the building of the suspension bridge at Pesth, the shoes of the piles which were drawn were found to be all displaced. They were afterwards riveted on to the piles. The gravel was so hard and compact as to shake the piles. To prevent them splitting screw-glands were used.

6298.



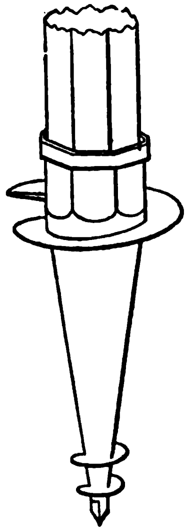
6299.



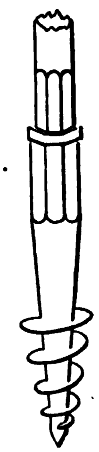
Timber Piles with Cast-iron Screw-points.—Several descriptions of cast-iron screw-points have been manufactured by Ransomes and May, of Ipswich. They are shown in Figs. 6300 to 6302. Fig. 6300 shows the largest size adapted for whole timber piles, which are often splintered and shattered, and even set on fire by the rapid blows of the steam pile-driver, when traversing compact ground, and when wrought-iron shoes are sometimes crushed into the timber, even in ordinary ground, with the force of the common pile-engine. The small screw-point opens the way for the conical part, and the larger screw not only draws the pile down, but when it has penetrated to a sufficient depth, affords an extended base. Fig. 6301 shows the shape adopted for railway signal posts, and Fig. 6302 that for telegraph posts. The advantages claimed for these screw-points are that they save several feet of timber, and that the general length of the pile can be reduced, as it will bear a greater weight, and offer a more solid base when introduced to a less distance than when at rest upon the ordinary sharp wrought-iron pointed shoes.

Rams or Monkeys.—In all cases, whether manual or steam labour is employed, the pile is driven by a blow which is given by a ram or monkey. This consists of a block of iron or wood, but more generally of the former material. Before describing it further, it will be well to inquire into the theory of its action. Writers on mechanics have not been able to agree on the precise manner in which the force of the blow given by the ram of a pile-engine should be estimated, and the question appears to have been greatly confused by confounding it with the effect produced in sinking the pile. It is well known that the sinking of the pile is by no means regular or proportioned to the friction opposing its descent as determined by theory. On the contrary, in defiance of all theory, a pile will sometimes sink more at the fourth or fifth blow than at the first or second, or perhaps more at the last blow than it did ten or fifteen blows before; and yet it is obvious that if we were attempting to investigate theoretically the resistance of friction, we must estimate this resistance to increase in some regular proportion to the depth to which the pile is driven in the ground.

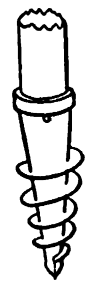
6300.



6301.



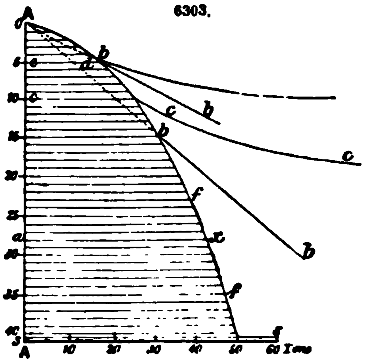
6302.



Practice, however, shows that occasionally the resistance is less than at a previous blow, when theory would point out that it is more. We therefore reject from our consideration every attempt to determine the actual effect produced by the force which we are able to exert on the pile. In fact, whether the blow produces any effect or not, the force exerted is still the same, and this is all that theory can determine, because the sinking of the pile depends on conditions of tenacity and consolidation of the ground to be driven into, which are too various and complicated ever to be capable of general expression.

Apart, then, from all consideration of the effect produced in sinking the pile, let us simply inquire the actual force with which the ram, in falling from a given height, strikes the head of the pile. Obeying the empirical law of accelerated velocity, the ram will fall through any space S in the time $\sqrt{\frac{S}{g}}$, where $g = 16\frac{1}{12}$ ft., the space through which a heavy body falls in one second of time. It is a fixed and well-established rule in mechanics, that the velocity acquired by falling through any given height is directly proportionate to the time of descent, and that the velocity acquired at the end of the first second of time is equal to $32\frac{1}{6}$ ft. a second; hence it follows that the velocity acquired by a body in falling through the space S is equal to $32\frac{1}{6}\sqrt{\frac{S}{g}}$. Then to find the force of the blow, the weight of the body is to be multiplied into this acquired velocity, which is not the velocity with which the body has fallen, but the velocity in feet a second with which it would fall during the next instant of time, were it not suddenly stopped by striking the pile. According to this formula, the following Table has been calculated, showing in one column the time of descent in seconds of any ram falling from 1 to 40 ft., and in the other, the force in tons with which a ram weighing 1 ton will strike, in falling from the same height. The force of the blow given by a ram of any other weight than a ton may be ascertained by this Table, by simply multiplying the number in the column headed Force in Tons, by the weight of the ram. Thus, if it is required to determine the force of a blow given by a ram of 16 cwt. falling from a height of 30 ft., opposite 30 we find the tabular number 43·9, hence 16 × 43·9 = 702 cwt. = 35 tons 2 cwt., the force required.

6303.



The diagram, Fig. 6303, is intended to represent, by means of the curved line *f f* the law according to which the force of the blow increases with the height from which it falls. For example, the distance *a x*, measured on the horizontal scale, will be 42·4 tons, the force with which a ram weighing 1 ton strikes when it has fallen from a height of 28 ft. The peculiar curve here shown is the result of that law by which the forces vary as the square roots of the heights from which the ram falls. If the forces varied directly as the heights, the straight lines *b b* would express the law of their increase; and if they varied as the square of the heights—a supposition which, erroneous as it is, has been entertained by some persons—the law of the forces would be expressed by a curve of an entirely different nature from the true one, namely, by the curves *c c*, according to which, if *e d* were the force for a height of 5 ft., *e e* would be the force for a height of 10 ft. The straight lines and the curves *c c* are, of course, both erroneous, the true scale for measuring the forces being afforded by the curved line *f f*, so that the distance *a x* of any point *x* from the vertical line A A, measured

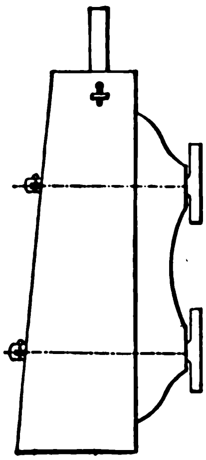
on the horizontal scale *s s*, will give the force of the blow correctly in the same manner as in Table I.

TABLE I.

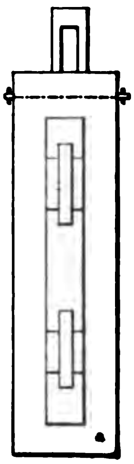
Fall of Ram in feet.	Time of Descent in seconds.	Force in tons for a Ram weighing one ton.	Fall of Ram in feet.	Time of Descent in seconds.	Force in tons for a Ram weighing one ton.	Fall of Ram in feet.	Time of Descent in seconds.	Force in tons for a Ram weighing one ton.
1	0·25	8·0	15	0·96	31·0	28	1·32	42·4
2	0·35	11·3	16	1·00	32·1	29	1·34	43·2
3	0·43	13·9	17	1·03	33·1	30	1·37	43·9
4	0·50	16·0	18	1·05	34·0	31	1·39	44·6
5	0·56	17·6	19	1·09	35·0	32	1·41	45·4
6	0·61	19·6	20	1·11	35·9	33	1·43	46·1
7	0·66	21·2	21	1·14	36·7	34	1·45	46·8
8	0·70	22·7	22	1·17	37·6	35	1·48	47·4
9	0·75	24·1	23	1·20	38·5	36	1·50	48·1
10	0·79	25·3	24	1·22	39·3	37	1·52	48·8
11	0·83	26·6	25	1·25	40·1	38	1·54	49·4
12	0·86	27·8	26	1·27	40·9	39	1·56	50·1
13	0·90	28·9	27	1·29	41·7	40	1·58	50·7
14	0·93	30·0						

Opinions vary as to the best weight of ram for driving piles with. A heavy ram with a short fall is much to be preferred to a light one with a long fall, the latter being more likely to split the pile; the blow given by the former is more solid, and, having a shorter fall, the blows are given quicker. The only objection is that two more men are required in using a 1½-ton ram than when a ton ram is used; but this objection is more than counterbalanced by both the quality and quantity of work done with the heavier ram. Again, in regard to the height of fall to be used, a short one is preferable to a long one, for an equivalent effect is not obtained for the extra amount of labour expended when giving a long fall. Take, for instance, a ton ram with falls of 6 and 12 ft.; the former would give a blow of nearly 20 tons, the latter one of nearly 28 tons. Here, to get an equivalent, the blow given through 12 ft. should be double that of 6 ft., but the momentum of falling bodies of equal weights must be as the square roots of the heights fallen through; therefore an equivalent for the extra labour of raising the ram is not obtained. It is not advisable to use a ram of a greater weight than 1½ ton, as it then becomes unwieldy, and requires so much force to raise and shift it.

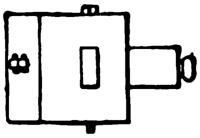
6305.



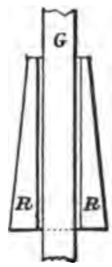
6304.

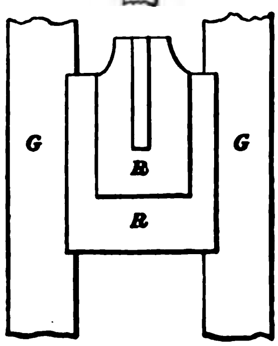


6306.



6307.





6308.

Rams, or monkeys, differ slightly in shape, in order to accommodate themselves to the guides of the engine in which they are driven. The ordinary shape is shown in Figs. 6304 to 6306, in front

elevation side elevation and plan. It is made straight on one side, that is, perpendicular to its base, and battered on the other face. The straight side slides against the guides of the engine, which it grips by means of the cheek-pieces attached to it. The weight of the ram represented in Figs. 6304 to 6306 is 22 cwt. In Figs. 6307, 6308, is shown another form of ram, in which two of the sides are battered. This ram R slides between a pair of guides G, G, of the engine, and has projections cast on the two straight or perpendicular sides, between which the guides pass. It is possible that the friction may be greater in this instance than in the other, although a steadier blow may be given. A ram seldom weighs less than 5 cwt.; but rams have been used weighing as much as 4 tons. Rams of oak, weighing about 30 cwt., were at one time very much employed, and do their work very well, without shaking or injuring the pile, as frequently occurs when iron rams are adopted.

The weight of the ram should be proportional to the sectional area of the pile to be driven. Piles having a diameter of 10 to 14 in. require to be driven with a ram weighing from 1000 to 1700 lbs. Sheet piles, with a breadth of 9 in. and a thickness of 3 or 4 in., require a ram weighing from 500 to 900 lbs. The weight of ram required for a pile of any given dimensions, with a certain fall, may be determined from the following equation;—Let F equal the height of the fall in feet, W the weight of the ram in lbs., B the breadth, and T the thickness of the pile in inches. Put L for the length of the pile in feet, and W_1 for its weight in lbs.; then for the value of W we have $W = W_1 \left(\frac{F \times W_1}{5\,B\,T\,L} - 1\right)$. If the pile is square, putting S for the length of one of the sides in inches, the formula becomes $W = W_1 \left(\frac{F \times W_1}{5\,S^2\,L} - 1\right)$. By the same formula, by simple inversion and reduction, the value of F, or the fall proper for a given weight of ram, can also be ascertained. Unless the value of L varies very considerably, it is scarcely worth while in practice to adopt a different weight of ram unless the job is an extensive one.

At the Brooklyn Graving Dock the rams were of cast iron, swelled out at the bottom to concentrate the weight at that point. They weighed generally about 2200 lbs., but others were used weighing only 1500 lbs. The fall was usually near 30 ft.; but some machines were tried with leaders, which gave a fall up to 57 ft. It was found by experiment that no advantage was gained by increasing the fall of the ram beyond 40 ft., as the friction on the ways then prevented any increased velocity to the ram when falling from a greater height. This result was obtained by tripping the ram at various heights, from 35 ft. upwards, until the maximum penetration of the same pile was ascertained. A few of the piles had to be driven with a follower or dolly, which was made of very tough oak, and well hooped at each end. The effect of the blows of the ram was about one-third as much as when directly striking the head of the pile.

The weight of rams varies considerably, and depends upon the circumstances attending each particular case. At the Montrose Harbour works, a ram of 12 cwt., with a maximum fall of 14 ft., gave six or seven blows a minute. It was found that a ram having a weight of 14 cwt. and a fall of 25 ft. shattered wooden piles, whereas one weighing 35 cwt., but with a fall of only 17 ft., did its work very well. At the construction of the Liverpool Docks, the weight of the ram was 13 cwt., and the fall 30 to 40 ft. The piles were of beech, and shod with wrought-iron shoes. This fall is very great, although the ram is comparatively a light one. When a light ram with a high fall is used, it will be found preferable to employ wrought-iron instead of cast-iron shoes. A heavy ram with a moderate fall always strikes a steadier and more even blow than when these conditions are reversed. It is well suited for driving cast-iron piles, notwithstanding that the precaution is always taken of using a dolly to save the heads of the piles. In calculating the weight of a ram by the formula already given for it, the nature of the ground, if of very exceptional character, must be taken into account. In very hard ground, the equation will hold true comparatively rather than absolutely, especially for large piles.

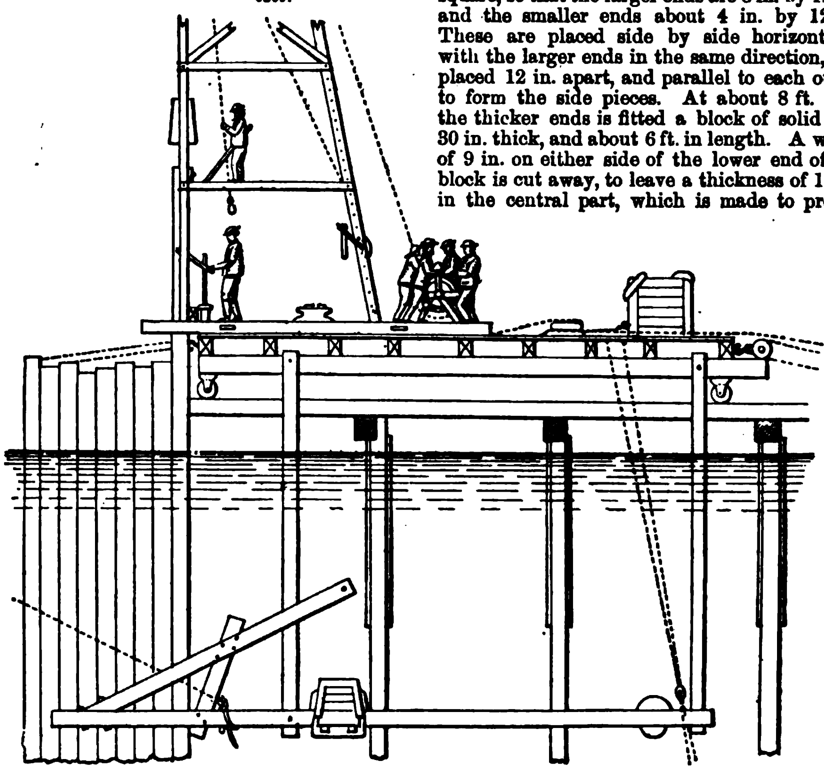
Driving Timber Piles.—In driving piles, the weight of the ram and its fall are not the only points to be considered. The rapidity with which the blows are given must also be taken into account. When piles are driven through sand or silt, the blows should be given very quickly, in order not to allow the ground to settle round them after each blow. The common ring-engine is often used for this reason in driving piles in the sand, but it is much better to use steam power. At the construction of the Pesth bridge, a couple of trial piles were driven through the bed of the river into the clay beneath. Both piles were of fir, but they differed as to hardness. The first pile was driven 20 ft. 6 in., and the second 22 ft. below zero, which gave 4 ft. into the substratum of clay. On leaving off driving, it took thirty blows with the monkey with a fall of 25 ft. to drive the first pile, and the hardest of the two, $\frac{1}{16}$ of an inch. The same number of blows with the same fall drove the second and softest pile barely $\frac{1}{4}$ of an inch. From twelve to sixteen blows were sufficient to upset the top of the first pile, so as to entirely destroy the effect of the blows until the damaged part was cut off and the pile rehooped. From five to six blows were sufficient to produce the same effect on the second pile. The outside of both piles was splintered and shaken a little, the first and harder the most. In driving the sheet piling for the same work, the ground was removed about 4 ft. in depth before a row of piles was pitched. They were then driven as far as they would go, which was about 3 or 4 ft., when the waling was fixed and strutted, and as much more of the gravel taken out as left the point of the piles 18 in. or 2 ft. in. A man was then employed with a kind of crowbar, with a spear-shaped head about 4 in. broad, to stir up and loosen the gravel opposite the pile which was being driven, and in this manner the whole bag was got down to within a foot or 18 in. of the clay, when more of the ground was taken out to allow of the lowest waling-piece being fixed and properly braced by the raking diagonal struts up to the tier above them. After this waling had been secured, the gravel was further loosened, and the pile driven until it had penetrated from 9 in. to 2 ft. 6 in., and in some cases 3 ft., in the clay

When the pile gets so deep in the ground that the head is below the level of the staging upon which the pile-engine rests, it is necessary to place on top of the pile a piece of timber hooped at each end. This is called a dolly or punch. A portion of the blow is probably absorbed by the dolly in its transmission to the pile.

Sheet piling in the form of caissons was employed extensively at the Pola Dock. A few round piles were first driven, by hand and steam pile-driving machines, from suitable floats, to which to secure the moorings. The sides were then staked out by driving 10 ft. apart, two and in some cases three rows of round piles. Straight, tapering round piles were chosen for this part of the work. The greater part of the sheet piling was of soft Italian, Styrian, and Austrian timber, 12 in. thick. Every piece was made quite straight upon the sides adjacent to or in contact with contiguous piles, and the piles were driven by ordinary pile-driving machines mounted upon travelling platforms provided with double-flanged wheels resting upon iron rails, which in turn were supported upon the tops of the longitudinal stringers. To the outer side of these longitudinal stringers the upper ends of the sheet piles were secured as fast as they were driven.

An ingenious apparatus for driving sheet piles accurately and evenly was designed by E. Towle, of New York, and used by him with great success at the construction of several important marine engineeering works at the Austrian naval station of Pola, on the Adriatic. The depth of the water, the light specific gravity of the material, which was of soft Italian, Styrian, and Austrian timber, and the character of the bottom, rendered the process more than usually troublesome and difficult. The machine, for want of a better name, was called a spider, and several of them were made and used about the work. It is shown in Fig. 6309. Two sticks of tapering timber are formed by sawing a log 35 ft. long and 12 in. square, so that the larger ends are 8 in. by 12 in., and the smaller ends about 4 in. by 12 in. These are placed side by side horizontally, with the larger ends in the same direction, and placed 12 in. apart, and parallel to each other, to form the side pieces. At about 8 ft. from the thicker ends is fitted a block of solid oak, 30 in. thick, and about 6 ft. in length. A width of 9 in. on either side of the lower end of the block is cut away, to leave a thickness of 12 in. in the central part, which is made to project down between the parallel side pieces, and the three are securely bolted together. From its upper end, which is about 5 ft. above the side pieces, the oak piece slopes toward the thicker ends, at an angle with the vertical of 30°, and is formed into a sort of throat, to receive the ends of the piles.

6309.



Two inclined side pieces, or cheeks of timber, 8 in. by 12 in., and 17 ft. long, are secured, one on each side of the oak throat-piece, near the top, and running down, rest upon the top of the long tapering side timbers near their thicker ends, to which they are securely bolted, as well as through the throat-piece and through each other. The side cheeks and oak block now form a funnel to receive the point of a pile, and to guide it through the 12-in. opening below. Two vertical timbers called hangers, 8 in. by 12 in., and about 20 ft. in length, are inserted between the side pieces, in the rear of the oak block, and about 20 ft. apart. They are each hinged at their lower ends by stout iron bolts passing through both the side pieces and the vertical hangers. The side pieces at the rear are clamped firmly together, with a distance piece between them 12 in. thick. Two

ordinary tackle-blocks, for receiving lateral guys, are now attached to the smaller ends of the side pieces, one on either side, and the guy-ropes are rove through the blocks; a 9-in. hawser being made fast to the side pieces near the oak block. The apparatus is next weighted with ballast iron, laid across the side pieces, until it will sink promptly, and it is now ready for use.

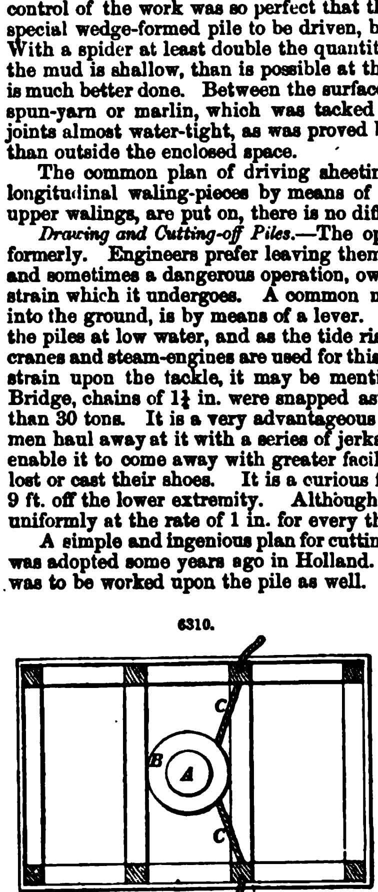
Suppose a few sheet piles to be already driven, and the pile-driving machine to be in proper position to drive another pile in the line, the spider is then advanced so that the two side pieces or horns of the machine are made to pass, one on either side, and clasp the sheet piles already driven; the hawser is drawn taut until the oak throat-block presses hard against the pile last driven and the lateral side guys, properly secured, are drawn up by the men, on the platform, until the machine below is in proper line, which is readily known if the hangers are vertical. All being now adjusted, a sheet pile is now raised in the piling machine, and is readily driven in line with those already down. The throat of the spider guides the point and the body of the pile to its place, and the elasticity of the hawser permits a pile or two to pass through without slacking. In the result, the control of the work was so perfect that the sheeting required, at intervals of from 20 ft. to 30 ft., a special wedge-formed pile to be driven, butt down, to keep the work vertical at the driving point. With a spider at least double the quantity of sheet piles can be driven a day in deep water, when the mud is shallow, than is possible at the same expense without such a contrivance, and the work is much better done. Between the surfaces of contiguous sheet piles was a single thread of ordinary spun-yarn or marlin, which was tacked at each end of the piles before driving. This made the joints almost water-tight, as was proved by the fact that water was often found 2 ft. higher inside than outside the enclosed space.

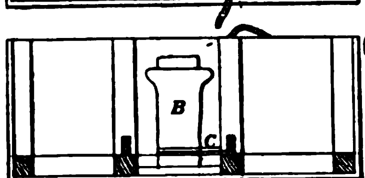
The common plan of driving sheeting piles under water is to connect the main piles with longitudinal waling-pieces by means of divers, or the diving bell. When these, as well as the upper walings, are put on, there is no difficulty in driving them perfectly tight.

Drawing and Cutting-off Piles.—The operation of drawing piles is not so frequently practised as formerly. Engineers prefer leaving them in the ground and cutting them off. It is a troublesome and sometimes a dangerous operation, owing to the liability of the tackle to break under the great strain which it undergoes. A common method of drawing piles, when they are not driven very far into the ground, is by means of a lever. In tidal rivers and estuaries, it is usual to moor barges to the piles at low water, and as the tide rises they are drawn out. On large bridge works, travelling cranes and steam-engines are used for this purpose, which afford great power. As a proof of the severe strain upon the tackle, it may be mentioned that in drawing some of the piles of Westminster Bridge, chains of 1¼ in. were snapped asunder. The strain upon these could not have been less than 30 tons. It is a very advantageous plan to fasten a rope to the top of a pile, and let a gang of men haul away at it with a series of jerks. These will loosen the hold of the pile in the ground, and enable it to come away with greater facility. Piles which are drawn are frequently found to have lost or cast their shoes. It is a curious fact that a pile has been drawn and discovered to have lost 9 ft. off the lower extremity. Although the stump was split all to pieces, yet the pile went down uniformly at the rate of 1 in. for every three blows for the last 7 or 8 ft. that it was driven.

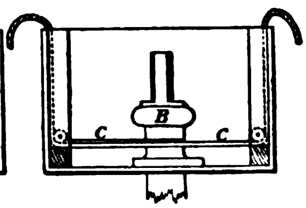
A simple and ingenious plan for cutting the heads of piles to any shape which might be required, was adopted some years ago in Holland. Not only were the heads required to be cut off, but a tenon was to be worked upon the pile as well. The apparatus consisted of a deal box, Figs. 6310 to 6312, well put together and made thoroughly water-tight by calking. The dimensions of the box were 6 ft. 6 in. long, 4 ft. 3 in. wide, and 9 ft. 3 in. deep. At the middle of the bottom there was a hole made large enough to admit the head of the pile A. Around this hole was nailed the open bottom of a sack B, made of stout canvas and strengthened with leather. Two cords C, C, were made fast at one end of each to the box, and the other ends were passed over pulleys in the sides. When it was required to cut off a pile, the box was put over it, and caused to descend as low as wanted by weights placed inside. Then, by the aid of the two cords, the lower end of the sack was drawn round the pile A, so as to form a completely water-tight joint. The water was emptied out of the box by a small hand-pump. A workman got in, turned back the canvas sack B, and after sawing through the pile, cut the head into any desired form.

6310.





6312.



6311.

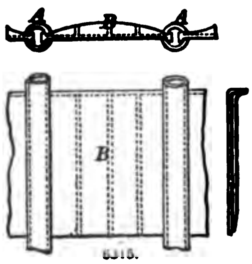
The piles forming the coffer-dams of the Thames Embankment were cut off by a pile-cutter designed for the purpose. The machine consisted of a platform upon a stout frame, resting upon four wheels, which travelled upon the rails before mentioned, and carrying a steam-engine with the requisite machinery for driving a circular saw, which was fixed at the lower end to an upright spindle, and adjusted to the proper level. The spindle was placed between the two rows of piles, and revolved in guides at the end of movable arms, so arranged that it would shift to either side of the dam by turning a handle and by the same motion it could be pressed towards the pile which

was being operated upon until it was severed by the saw. Two piles were usually cut off on each side before the machine required to be moved backwards on the rails. When the way was clear for the pile-cutter, and a sufficient length of dam dredged, sixty piles could be cut off in a day, but the excavators could not keep pace with the pile-cutter, and the average number of piles actually cut off did not exceed thirty-six daily. The machine was partly devised by Charles Murray, of London, but the motion which regulated the position of the spindle was entirely the invention of Murray. In using the circular saw for cutting off piles below water, at depths of 15 to 30 ft. below the surface, considerable difficulty has sometimes been experienced by the saw nipping. When this occurs the common saw can be employed, worked by hand labour from a diving bell, with ropes attached to the heads of the piles to draw them asunder as the cuts are made.

Cast-iron Piles.—In the Solway Viaduct, which is more than a mile in length, it was originally intended to use the screw pile, but on trial it was found that after getting through a depth of about 4 ft. of sand, there was so very hard a substratum of gravel mixed with stiff clay beneath, that the screws would not penetrate it, and the pile represented in Fig. 6313 was adopted. Over 1200 of these piles were driven. They were of cast iron, 12 in. diameter, and with the exception of some half hundred were driven from positions. One of these piles, 20 ft. in length, after being pitched into position, was generally driven down 18 or 19 ft. in thirty minutes, having received from twelve to fifteen blows a minute, from a monkey weighing 25 cwt., and with a fall of 5 ft. A timber dolly was used between the pile and the ram, with a copper ring between the shoe of the dolly and the pile-head. Six piles were generally got down in two tides. In Figs. 6314, 6315, are shown the iron piles and plates adopted in the construction of new Westminster Bridge. The piles A were 15 ft. long, and 15 in. in diameter, and were driven into the river bed by an ordinary pile-engine at intervals of 7 ft. In the spaces between the piles, cast-iron plates B were driven. The plates were 1¼ in. in thickness, and fitted the grooves in the piles exactly. The plates were stiffened by vertical ribs R, R, R, and by a horizontal rib at top.

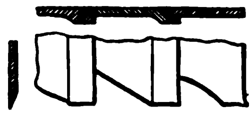
6313.

6314



6315.

6316.

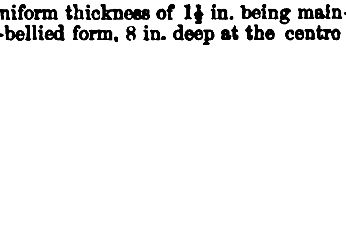


6317

Leach has used cast-iron plates to advantage in the construction of a lock near Oxford. The piling was made of cast-iron plates 12 ft. long, 2 ft. wide, and 1¼ in. thick, sharpened at the edge to ⅜ in. The plates, which are shown in Figs. 6316, 6317, fitted closely over one another. By these means the lock has its sides permanently lined with iron up to the water level. The guide-piles were of timber, and together with some iron ties to the shore, were sufficient to keep the iron piling in position while driving.

In the Dovey Viaduct a timber dolly was interposed between the monkey and the cast-iron splice, instead of the mass of lead which had been specified for, and which had been used with success in another case of an estuary crossing, in which the masonry piers were supported by bearing piles wholly of cast iron, and driven precisely as timber piles. The bearing piles were of cast iron, the cross-section of which measured 16 in. by 10 in., and consisted of a longitudinal web, extending 16 in., crossed by two transverse webs of 10 in. each; the cross-section, which was adopted from some similar works in the North of England, was a very advantageous one, as the disposition of the longitudinal and transverse webs caused it to drive particularly true, and afforded a large periphery of frictional bearing surface. These cast-iron piles were 42 ft. in length for the piers of the central opening, and 32 ft. for the other piers, the 42-ft. piles were driven 25 ft. into the bed of the channel, which was of London clay; and thence to their heads, which were driven down level with low-water mark, was 17 ft.; the heads of the piles were rectangles of 16 in. by 10 in., formed by flanges filling up the spaces between the longitudinal and transverse webs. These piles were designed to be driven 4 ft. apart from centre to centre, but were really driven somewhat closer. At low-water mark they were surmounted by two courses of Yorkshire flagstones, above which the piers were carried up in brick in cement. In driving the piles a mass of lead was interpolated between the monkey and the pile-head, and not a pile was broken in driving.

6318. 6319.



6320. 6321.

In the building of the Lowestoft Harbour there was erected a wall more than 1000 ft. in length, altogether of cast-iron piles, of the section shown in Figs. 6318 to 6321. Many experiments were made to obtain the best form of pile, and finally they were cast 30 ft. long, 18 in. wide, and of a thickness greater at the centre than the ends, a uniform thickness of 1¼ in. being maintained at the edges by means of fillets. The rib was of fish-bellied form, 8 in. deep at the centre

and to counteract the tendency this form has to force the piles outward, the lower part of the rib was made in steps, as shown in Fig. 6321, and the cutting edge of the toe was one-sided. The piles were driven close together, edge to edge, clamps of wrought iron 5 in. × 4 in. × ⅝ in. being riveted to the sides to act as guides. The heads of the piles were thickened out to 3 in., and were strengthened by ribs, as in Figs. 6318, 6319; the bolts were provided for tying the piles to a horizontal oak waling behind. The piles were driven into the bed of the sea to a depth of 10 or 12 ft. by an ordinary pile-engine, and it was found that by using a very heavy weight and a thin piece of elm on the pile-head to receive the blow, few of the castings were cracked or broken.

Duration of Iron Piles.—Objections have been made to the use of iron under water, in consequence of the oxidization which then takes place, not only in sea, but also in river water. The introduction of cast-iron piles and plates is of such comparatively recent date, that as yet there has not been sufficient time to prove their value in practice; but the experiments of Robert Mallett have quite overruled the objections just mentioned. Mallett experimented upon specimens of Scotch, Welsh, Staffordshire, and Irish cast irons. He immersed specimens of cast iron close to the mouth of the Great Kingstown main sewer, with a bottom of soft putrid mud. The result of this experiment showed that it would take 506 years to eat through an iron plate 1 in. thick acting on one surface, and 253 years if both surfaces were exposed. Cast iron was then immersed in the sea-water at Kingstown Harbour, and it was found by that experiment that it would take 530 years to eat through an inch thickness where one surface was exposed, and 265 years if both surfaces were acted upon. The next experiment was made in foul river-water, on a bottom of putrid mud, at the junction of the Poddle River. The result here was that it would take 1200 years to eat through an inch thickness of iron, and 600 years if both sides were exposed to the action of the water. Mallett also immersed the different irons in clear fresh river-water for 732 days. In this case he found that the mean corrosion to the square inch of surface exposed was 1·011 grain; and as the weight of a cubic inch of cast iron is 1841 grains, it would take 1820 years to eat through a plate of iron 1 in. thick if both surfaces were exposed to the action of such water. These experiments show that iron is sufficiently durable for the purpose; for even in the most disadvantageous locality, exposed to the effects of sea-water, combined with the contents of a main sewer, an iron plate 1 in. thick, with one surface exposed, as would be usually the case, would last for several centuries.

In the construction of the harbour of Lowestoft, to which allusion has already been made, iron piling was used as a substitute for timber, which would have been destroyed by the teredo. It was supposed by some engineers that the iron would become softened by the action of the water; but after the piles had been in position for forty years, the iron was found to have deteriorated but very little. The deterioration took place at the edges of the pile, at places where the runners had broken off, and where the original skin of the casting had been removed. It is a fact well known to engineers, that cast iron is far more liable to suffer from the action of the weather and sea-water when it has once lost its original back or skin. It is said also that its strength is impaired from the same cause.

Supporting Power of Piles.—There are three distinct purposes for which piles are used. First, to consolidate ground which is not firm enough to support in its natural state the intended superstructure; secondly, as a medium of support, or to transfer the weight down to a solid stratum, when the upper stratum is not solid enough to carry it; and, thirdly, when the support is chiefly derived from the adhesion of the material into which they are driven, and slightly from their sectional area.

At the graving dock at Brooklyn, New York, the centre piles are subjected to a pressure varying from 10 to 20 tons. Altogether there were seven thousand piles driven, in rows 2 ft. 6 in. apart, and at transverse distances of 3 ft. from centre to centre. The main piles were round spruce spars, very straight, from 25 to 45 ft. in length, having an average length of 32 ft. They were not less than 7 in. in diameter at the smaller end, and on an average 14 in. in diameter at the larger end. The heads of the piles were always protected in driving by bands of iron 3 in. × 1 in., and occasionally iron shoes were used. But these did not increase the penetration, as the resistance arose principally from the lateral friction, and the tenacity of the pointed wood was sufficient to displace the material at the bottom. During the progress of this portion of the work, a careful record was kept, which showed the distance moved by every blow on every pile used on the structure, and the weight and fall of the hammer at each blow. It was thus ascertained that the number of blows required to drive 6539 piles in the foundation an average depth of 32 ft. was ten and one-third to each foot of pile, and the distance moved uniformly diminished from the first to the last blow, ranging at 8 in. at the commencement to no movement at the end, and the average distance driven by the last five blows was 1 in.

As before remarked, the pile derives its support mainly from the frictional surface in contact with the earth, which is measured by the force of the blow, due to the weight and velocity of the ram. The ram does not fall in free space, but meets with considerable resistance from the friction with the ways. This resistance is also materially increased when the piles are driven on the cant, and the machine is not in a vertical position. In wet foundations the material obtains a degree of fluidity when disturbed by the operation of driving, which lessens the resistance to the penetration of the pile; but the greater density of the earth compared with that of the water causes it subsequently to settle in close contact with the sides of the pile, and if not afterwards disturbed, gives a greater coefficient of support than if the same pile had been driven through the same kind of material in a dry state. When piles of small lateral dimensions are used, the vibration caused by the blows enlarges the passage and loosens the earth round them. A good deal of the power is probably absorbed in this manner, although the penetration may be increased.

During the construction of the dock in question, experiments were made at different times to ascertain the weight which the piles driven in the manner described would sustain. For this purpose, one end of a lever of oak timber 60 ft. in length was firmly secured to a cluster of piles, with a short arm resting on the trial pile. The bearings were angular steel bars resting on plates of iron

with planed surfaces. The outer end of the lever was slowly weighted with successive weights, which towards the latter part of the trial were allowed to remain for several hours, and in a few cases a whole night. A number of coffer-dam and foundation piles were drawn by a similar process, and the power necessary to draw them also determined. Many of these trials were made on piles of nearly the same size, and driven in exactly the same manner, and the results were in all cases nearly alike. The weight required to move a pile driven 33 ft. into the earth to the point of ultimate resistance with a ram weighing 1 ton and falling 30 ft. at the last blow, was 125 tons. The piles experimented upon had an average diameter of 12 in. As these trials were continued until the final weights applied produced a visible movement of the pile, and as some allowance must be made for the friction and imperfection of the lever attachments, and from the support of the sectional area of the pile, it was considered that the extreme supporting power of the pile, due to its frictional surface, was 100 tons, or 1 ton a superficial foot of the area of its circumference. From an analysis of these experiments, the following general laws seem to have obtained;—First, that the effect of lengthening the fall of the ram was to increase the sustaining power of the pile in the ratio of the square root of the fall; second, that by adding to the weight of the ram, the sustaining power of the pile was increased by 0·7 to 0·9 of the amount due to the ratio of the augmented weight of the ram, and, third, that a pile driven by a ram weighing 1 ton and falling 30 ft. will sustain an extreme weight of 100 tons.

The following formula, based upon these data, is applicable to rams weighing from 1000 lbs. to 8000 lbs., and falling from 20 to 40 ft.;—Let W represent the weight of the experimental ram, and W_1 the weight of any other ram. Put F for the fall of the experimental ram, and F_1 for that of any other ram. Let S represent the extreme supporting power of a pile driven by the ram, having a weight equal to W, and a fall equal to F and S_1 the supporting power of a pile driven by a ram having a weight equal to W_1 and a fall equal to F_1. In the experiment, $W = 1$ ton, $F = 30$ ft., and $S = 100$ tons. W_1 and S_1 are in tons, and F_1 in feet. With the same weight of ram as in the experiment, and with any other fall, we have the proportion $\sqrt{F} : \sqrt{F_1} :: S : S_1$, from which $S_1 = \frac{\sqrt{F_1} \times S}{\sqrt{F}}$. Substituting in the equation the values for the several terms, it becomes $S_1 = \frac{\sqrt{F_1} \times 100}{5·47}$, whence $S_1 = 18·25 \sqrt{F_1}$. In the second case, let the fall remain constant, but the weight of the ram vary, and the value of S_1 will be given by the expression $S_1 = 0\ 8 \left(\frac{S \times W_1}{W} - S\right) + S$. This equation may be put in a simpler form, and we have $S_1 = \frac{S\,(0·8\,W_1 + 0·2\,W)}{W} = S\,(0\ 8\,W_1 + 0\ 2)$, since $W = 1$. Finally, substituting for S its value of 100 tons, we have $S_1 = (80\,W_1 + 20)$. A combination of the two results gives $S_1 = 80\,(W_1 + 0·228 \sqrt{F_1} - l)$.

M'Alpine states that under the most favourable circumstances the pile should not be loaded with more than one-third of the weight given by his formula; and where there is any danger of a future disturbance of the material around the pile, or where there is any vibration in the structure which may be communicated to the piles, the load imposed should not exceed one-tenth. The bearing support, due to the sectional area of the pile, has not been taken into account in these calculations, as it forms so small a portion of the support. From numerous experiments, the results obtained gave from 5 to 10 tons of pressure on the superficial foot of the pile.

There are several other formulæ for determining the pressure a pile will safely bear, but they must be received with caution, as practice proves that the nature of soils is so exceedingly variable as to almost set theoretical calculations in this respect at defiance. Molesworth gives one as follows;—"The pile will safely bear, without danger of further subsidence, as many times the weight of the ram as the distance which the pile is sunk the last blow is contained in the distance which the ram falls in making that blow divided by eight, provided the pile moves uniformly at several of the last blows." Mathematically this rule may be thus expressed;—Let S_1 equal as before the supporting power of the pile, and W_1 and F_1 the weight and fall of the ram. Put P for the penetration due to the last blow, and we have $S_1 = \frac{W_1 \times F_1}{8 \times P}$. A formula nearly agreeing with that given by Weisbach is $L = W \left(\frac{W}{W + W_1}\right) \times \frac{H}{D}$, in which W is the weight of the ram in tons, W_1 the weight of the pile in tons, H the height of the fall of the ram in feet, and D the depth which the last stroke drives the pile. The following is a comparison of the results obtained from M'Alpine's formula and others. In Weisbach's formula $S_1 = \left(\frac{W_1}{W \times \omega}\right)^2 \times \left(\frac{\omega F_1}{P}\right)$, in which the terms are the same, except that W is expressed in lbs., and ω represents the weight of the pile, and P the average penetration of the pile due to the last ten blows of the ram. By assumption $\omega = 560$ lbs., and $P = 0·04$ ft., although it was really nil in the dock experiment. From this we have $S_1 = 120$ tons, or if P is reduced to 0·01 ft., $S_1 = 480$ tons. By Molesworth's formula $S_1 = \frac{W_1 \times F_1}{8 \times P} = 90$ tons; or if $P = 0·01$, then $S_1 = 360$ tons. From M'Alpine's formula $S_1 = 80\,(W_1 + 0·228 \sqrt{F_1 - 1})$, we obtain $S_1 = 100$ tons, when $P = 0$. According to Weisbach's formula, the pile for safety should not be loaded with more than from one-hundredth to one-tenth of this result. Molesworth's formula gives the safe load. It appears that the supporting power which is derived from the frictional surface of large cast-iron piles, 6 ft. in diameter sunk from 20 to 30 ft. in rocky gravel, is about half a ton to every superficial foot of frictional surface.

The following formula, which is by Rankine, shows the relation which exists between the blow required to drive a pile to a given depth, and the greatest load that it will bear without sinking farther, supposing it to be supported by a uniformly distributed friction against its sides. Let W be the weight of the ram, H the height from which it falls, D the depth through which the pile is driven by the last blow, P the greatest load it will bear without sinking farther, S the sectional area of the pile, L its length, and E its modulus of elasticity. Then the energy of the blow is thus employed. $W \times H = \frac{P^2 \times L}{4ES}$ is the portion employed in compressing the pile, and $P \times D$ employed in driving it. From which $P = \sqrt{\left(\frac{4ESWH}{L} + \frac{4E^2S^2D^2}{L^2}\right)} - \frac{2ESD}{L}$. Piles are generally driven until P as computed by this formula is between 2000 and 3000 lbs. to the square inch of the area S; and as their working load ranges from between 200 to 1000 lbs. per square inch, the factor of safety against sinking is from 3 to 10. The factor of safety against direct crushing of the timber should not be less than 10. According to some of the best authorities the test of a pile having been sufficiently driven is, that it shall not be driven more than one-fifth of an inch by thirty blows of a ram weighing 800 lbs., and falling 5 ft. at each blow. The total mechanical energy of this whole series of blows is equal to $30 \times 800 \times 5 = 120000$ foot pounds. The object of driving a number of piles uniformly which are to bear together a distributed load, is to ensure that each pile shall support its proper share of the load. If some datum were not adhered to with respect to the point at which the driving of all the piles should cease, they would be driven down to different depths, and would not have the same supporting power. If the weight were uniformly distributed over the whole number, and some were to yield, an undue pressure would be at once thrown upon those which stood fast; and it is quite possible they might yield, and thus the whole foundation be destroyed piecemeal. It must not be supposed that the supporting power of piles is necessarily proportional to the depth to which they are driven. A great difference in penetration exists at very small distances between piles. We have known main piles driven at intervals of only 5 ft.; and while some went down with facility, others not 10 ft. from them were got down with considerable difficulty.

For practical purposes there can hardly be a better formula for calculating the bearing power of piles than that of R. Sanders. Let W equal the weight which may be safely placed on the pile, R equal weight of ram, F the fall of the ram in making the last blow, and D the distance the pile sinks with the blow, then $W = \frac{R \times F}{8 \times D}$. In comparing the results obtained, and taking as an example the driving of one complete work from practice, Beazeley found that the average supporting power of the piles as calculated by Rankine's formula was 5·20 times, by Weisbach's 5·24 times, and by that given by M'Alpine 0·303 times that obtained from Sanders' formula. Rankine, however, states that the load to be placed on a pile when it is driven to the test should be from one-third to one-tenth, which amounts on the average to dividing his absolute results by the ratio 5·20. Weisbach stated that the load should be from one-tenth to one-hundredth, which appears out of all reason. But as his absolute result, comparing it with practice, tallied very closely with Rankine's, the ratio 5·24 may fairly be taken as a divisor. While Rankine's and Weisbach's formulæ practically agree with that of Sanders, that of M'Alpine indicates too low a result, being only 0·303 of the others.

TABLE II.

No. of Pile.	Depth in Ground.	Total Length of Pile (L).	Value of P = L × 0·22.	Value of D.	Value of F.	Sanders' Formula.	Rankine's Formula.	Weisbach's Formula.	M'Alpine's Formula.
	feet.	feet.	tons.	feet.	feet.	Value of W in tons and decimals.			
1	15·00	20·00	0·440	0·0573	10·58	23·09	111·68	128·22	5·93
2	13·00	18·00	0·396	0·1094	11·83	13·52	87·03	77·75	6·27
3	12·00	17·00	0·374	0·0883	10·00	15·00	91·41	87·72	5·77
4	12·50	17·50	0·385	0·0833	10·50	15·75	94·52	91·34	5·91
5	13·25	24·75	0·544	0·0313	10·00	40·00	122·04	206·93	5·77
6	13·00	24·75	0·544	0·0677	11·50	21·23	103·79	109·53	6·19
7	13·67	25·17	0·544	0·0885	10·00	14·12	81·37	72·71	5·77
8	16·00	27·50	0·605	0·0573	10·00	21·82	97·69	109·31	5·77
9	15·58	26·33	0·579	0·0625	10·00	20·00	95·52	101·33	5·77
10	16·00	27·00	0·594	0·0625	10·00	20·00	94·82	100·38	5·77
11	16·75	27·50	0·605	0·0625	10·00	20·00	94·33	99·69	5·77
12	17·50	28·25	0·622	0·0469	10·00	26·67	103·97	131·45	5·77
13	14·67	24·17	0·532	0·0729	10·00	17·14	91·05	89·42	5·77
14	13·50	23·50	0·517	0·0833	10·00	15·00	85·47	79·14	5·77
15	17·67	26·17	0·576	0·0678	10·00	18·46	92·31	93·71	5·77
16	17·25	25·75	0·567	0·0573	8·00	17·45	85·06	89·11	5·77
17	18·25	23·73	0·522	0·0781	10·00	16·00	88·28	84·09	5·77
18	18·67	24·17	0·532	0·0833	10·00	15·00	84·93	78·33	5·77
19	14·92	20·42	0·449	0·0833	10·00	15·00	88·16	82·82	5·77
20	16·25	21·75	0·479	0·0729	10·00	17·14	93·45	92·72	5·77

In Table II. are given the supporting power of piles calculated by the aid of various formulæ. The letters have the following significations;—W equals the safe load on the pile in the formulæ of

Sanders and M'Alpine, and the theoretical load in those of Rankine and Weisbach. F equals the fall of the ram in making the last blow, D equals the distance the pile sinks with the last blow. R is the weight of the monkey, which is a constant quantity and equal to 1 ton. L equals the total length of the pile, and P equals its weight. The sectional area of the pile is represented by S, which is also a constant quantity and equal to 0·7 ft. The modulus of elasticity for slaty gum timber which is constant to every calculation, is equal to E, and has a value of 331,100 inch pounds. The mean results of the last four columns are as follows;—Sanders 19·12, Rankine 99·34, Weisbach 100·28, M'Alpine 5·80; and the corresponding ratios are Sanders 1·00, Rankine 5·20, Weisbach 5·24, and M'Alpine 0·30. The dimensions are all in feet and decimals.

The mean results arrived at by the different formulæ are Sanders' = 19·12, Rankine's = 99·34, Weisbach's = 100·28, and M'Alpine's 5·80; and the corresponding ratios are Sanders' = 1·00, Rankine's = 5·20, Weisbach's = 5·24, and M'Alpine's = 0·30.

When a pile is driven into the ground, it will bear a certain weight without sinking. It will resist further penetration with a certain force. Let this force be represented by F. The amount of work done when the pile is driven, is equal to this force multiplied by the distance the pile is driven. But this distance D and the work done in driving the pile equals F × D. But D is a known quantity, and F could be ascertained if the amount of the work expended in driving the pile could be determined, and that amount divided by D. Now, the mechanical force of a blow of the monkey is equal to its weight multiplied by the distance through which it falls. Making these equal respectively to W and H, and assuming that the whole force is exerted in driving the pile, we have the equation $P \times D = W \times H$, from which $P = \frac{W \times H}{D}$. In Rankine's formula the force of the blow expended in compressing the pile is given by the expression $\frac{F^2 \times b}{4 E S}$. Representing by M the force necessary to overcome the elasticity of the ground, and the equation becomes

$$W \times H = F \times D \times \frac{F^2 \times l}{4 E S} + M.$$

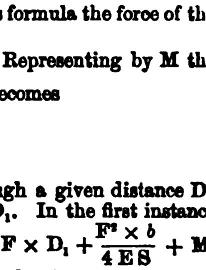
Let the ram fall through a given distance H, and let it drive the pile through a given distance D; and also through another distance H, and drive the pile another distance D_1. In the first instance we have $W \times H = F \times D + \frac{F^2 \times b}{4 E S} + M$; and in the second, $W \times H_1 = F \times D_1 + \frac{F^2 \times b}{4 E S} + M$. Subtracting the one from the other gives $W(H_1 - H) = F(D_1 - D)$; and, finally,

$$F = \frac{W(H_1 - H)}{(D_1 - D)}.$$

If it is required to find the supporting power of a pile, let it be first ascertained what distance it is driven through by the ram falling from a certain height, and then the distance corresponding to a blow from the same ram falling through a greater height. The sustaining power of the pile will be found by multiplying the weight of the ram by the difference of the falls, and dividing the product by the difference of the distances the pile is driven. Instead of taking a couple of blows only, the mean result of several should be ascertained, as the supporting power will be practically constant for a few inches of penetration, except in very springy ground.

An ingenious method for determining the force expended in driving a pile was devised by Heppel, depending upon the fact that if an exact register of the motion of the ram could be obtained, that is, its exact position at given intervals of time, the force which acts upon it can also be determined. A piece of drawing paper was stretched upon a board, as in Fig. 6322, and a pencil attached to a strong spring, fixed to an independent support, and having sufficient range when let go to draw a horizontal line completely across the paper which was divided by vertical lines into equal spaces. A detent held back the spring, and was capable of being released at the time when the board descending vertically passes a certain point. To ascertain at what intervals of time the pencil, in drawing a horizontal line by the action of the spring, passed the several vertical lines, the board was fixed in a vertical slide, so that it might have a fall of 3 or 4 ft.; and the spring was fixed opposite to it, so that on reaching a certain point it released the detent. It was then first moved slowly down to this point till it touched the detent, and the pencil drew a horizontal line. Next it was allowed to drop through a given distance, and on passing the same point, it had now a known velocity which, for the small interval taken up in observing the line, might be regarded as uniform. This velocity being compounded with that of the spring, the line drawn was no longer horizontal, but deviated from that direction in a certain curve. The interval of time which the board took in falling through any vertical distance in Fig. 6322, was ascertained from its known velocity, and as the pencil passed a certain horizontal distance in the same time, the times of its passing all the vertical lines became known. The instrument was now ready for use. In making an experiment the board was fixed to the pile near its head. The spring and pencil were fixed to an independent support, and the detent was so adjusted as to be released the moment the slightest motion in the pile took place. A curved line was thus drawn, and the times at which the pencil must have arrived at each of the vertical lines being already known, the times at which the head of the pile was at the level of their intersections with the curve, became known. As the motion of the ram may be taken to be the same as that of the pile-head, which it would be at any rate up to the point of maximum pressure, which is the most essential point to determine, the velocity of the latter at any

6322.



moment can be computed, and consequently the force to which it must at that instant have been subjected.

Pile-driving Machines.—Before commencing to drive permanent or bearing piles, it is necessary to construct good staging and strong guide-timbers, without which it is impossible to drive them properly, more especially sheeting piles. There have been so many different kinds of pile-driving machines invented, some varying considerably, and others but slightly in their details, that it would be difficult to enumerate them; a few, however, may be selected of those which have been most generally used. The ringing machine is one of the earliest invented. Its name was derived from the similarity in the mode of using it, to that of the ringing of church bells. This kind of machine was used by the celebrated French engineer, Perronet, at the construction of the bridge of Orleans. It had a ram weighing 10 cwt., which is much heavier than those used with ringing machines at present. The weight now employed rarely exceeds 3 or 4 cwt., in consequence of the number of men required to raise it in this manner; and it is now only used for light work. One was employed at new Westminster Bridge, to drive thin sheeting piles for a small temporary dam at the middle abutment. The weight of ram used there was little over 1 cwt., five men worked it, giving fifteen to twenty blows a minute, and about 5 or 6 ft. fall. The rams used are made of oak, or elm, hooped with iron. The ringing machine was the usual mode of construction till of comparatively recent date. At one time horses were employed to raise the ram. They were used in driving the guide-piles at the old Westminster Bridge. The machine they worked had a ram weighing nearly 16 cwt., which, with a 20-ft. fall, and by the help of two horses, gave forty-eight blows an hour, or four blows in five minutes; with three horses it gave seventy strokes an hour. After this machine had been used for some time, when the pivots had been rubbed smooth, and the stiffness of the ropes destroyed, three horses going at an ordinary pace gave five strokes in two minutes, with an average fall of 9 ft. Perronet also used horses for driving piles, with a machine worked by means of an armed wheel and a drum. This machine could be fixed on a boat, and the ram was raised by means of a rope passed round the armed wheel, and attached to a horse on the shore. De Cessart used another kind of machine at the bridge of Saumur. In it the axis was 10 in. diameter, and the wheel 12 ft., with trundles to turn it; eight men employed at this wheel raised, at three turns a stroke, a ram, rather more than 13 cwt., 6 ft. high, which was then unhooked.

The pile-driving machine in general use at the present time is much superior to any of the foregoing, both as regards general construction, and the ram used, which is made of cast iron, and is much heavier than was formerly employed.

Of late years steam has been extensively used as a power for raising the ram; among the machines which are worked by steam are the following given in Table III., showing the weight of ram, number of blows a minute, and height of fall.

TABLE III.

	Weight of Ram.	Height of Fall.	Impact.	Blows a minute.
		feet.	tons.	
Common	1¼ ton.	6	24¼	5
Nasmyth's	15 cwt. Total Weight of Machine 3 tons.	3	10·4	60
Scott's	1¼	6 to 15	29·4 to 46·5	15 to 20
Sisson and White's	1	5	17·6	10

Of these Sisson and White's possesses some especial advantages. It is very portable, does good work, can be easily attached to any common piling machine, and made the means of its own locomotion. Steam pile-driving is the most advantageously employed when rows of piles are required to be driven, as for coffer-dams, or in driving sheeting for quay walls; but where it is necessary to drive piles very accurately, as in bridge foundations, more especially for iron piles or plates, the ordinary crab machine worked by manual labour is the best.

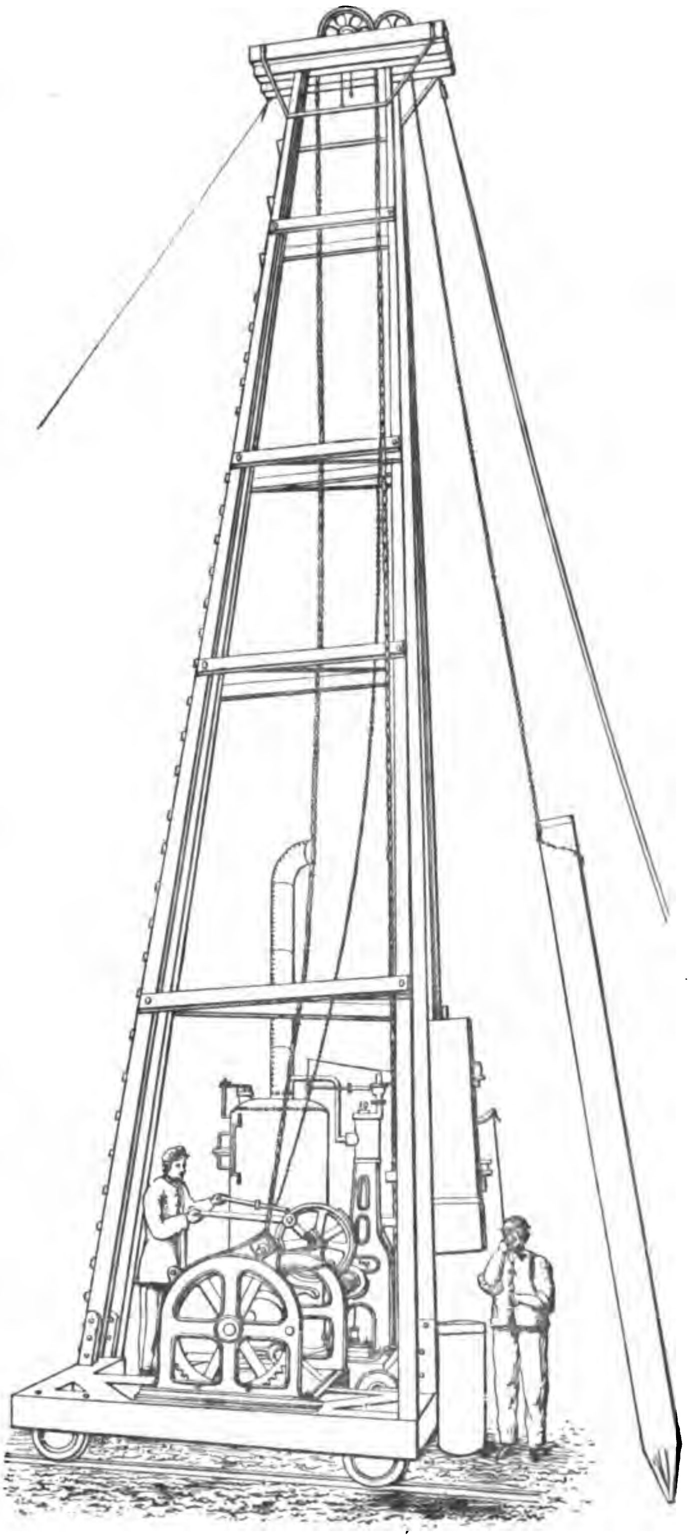
Sisson and White's machine, Fig. 6323, is easily moved, and by a contrivance in the carriage part can be transferred to other lines at any angle with great facility; it requires four men to work it, and consumes about 4 cwt. of coal or gas coke in ten hours. The total weight of the driver and boiler is 6 tons, including the ram and mounting, which are 20 cwt. The bottom framing of the driver is 8 ft. square. Its comparative lightness, and the small space it occupies, make it capable of being worked in any position or circumstances in which a common hand-machine can be put, either on land or afloat. The machine is moved by fastening the end of a rope ahead, passing it over a roller under the winch, and taking a turn round the barrel.

The pile is quickly pitched by attaching a common chain to the pile-head, and the ram usually falls about twelve times in a minute, with a 6-ft. lift. The ram is lifted by means of an eccentric fixed in an opening made in the centre of it, and is made to revolve by a lever, to the outer end of which a cord is attached, and, on being drawn downwards, a bolt is shot out into the open link of the pitched chain in its upward motion. The bolt is withdrawn by the other end of the lever striking against a staple fixed in the front of the guide-pieces, and the ram thus released then falls on the pile. The height of the machine in the annexed drawing, Fig. 6323, is 40 ft., and will pitch a pile 34 ft. long on ground the same level as that on which the machine stands; this height is found to be sufficient for general use, but machines of greater height can be constructed. Telescope drivers are made by which piles can be driven in a tideway down to a depth of 30 ft. below

the stage on which the machinery stands, the ram driving quite down to the ground without using a dolly, to dispense with which is a great advantage.

In setting the machine to work, a centre line should be struck from end to end, and a template made the shape of the point, the centre line of which should line with that of the pile, and the line then scribed. Point the pile with the saw, so as to have a stump point, about 8 in. square, forming a seat for the shoe. The length of the point in timbers 14 in. square, should be 2 ft. 6 in., the point of the shoe should be of solid iron, and the four straps, 18 in. long, and of iron 2 in. by ½ in., nailed on; the strength of the shoe should vary, depending on the nature of the ground, and weigh from 12 lbs. to 30 lbs. The driving hoop to the head of the pile should be of iron, 4 in. by 1 in., truly fitted and driven on by the ram, and in its outside dimensions a little less than the pile in every direction. The pile is held in position by a bolt 1½ in. in diameter, called a toggle-bolt, passing through the pile about 2 ft. from the head to the back of the uprights, and there fixed with an iron plate, nut, and screw · a piece of hard wood must also be placed to fill up the space between the uprights, through which the toggle-bolt also passes, to keep the pile in its position. The ½-in. chain with which the pile is pitched, when not in use, is fastened to one of the diagonal stays, to be kept out of the way. It will be observed that the pulley with the semi-circular groove at the head of the driver, is for the use of this chain. While the pile is being

6323.



pitched the ram is wound up to the top, or as high as is necessary, and held there by a bolt passing through the uprights, and when the pile is in position then gently lowered upon it. By the lowering of the screw at the foot of the ladder, the incline of the uprights is regulated to suit the batter at which the pile may have to be driven. It will be seen by the holes in front of the guide-pieces to receive the striking-off staples, that the ram need not be lifted higher than these distances before it is struck off, and it is recommended that with a ram above 1 ton weight it should never fall more than from a height of 5 or 6 ft. on a pile of fir timber; the work is quicker done and the wood preserved. To work the driver it requires four men only, namely, one to drive the winch, one on the stages to shift the striking-off staple, one to attend the pile, and one to work the catch. Two stout boys would do to shift the staples, and work the catch. The catch is worked by a piece of strong cord fastened to the hole on the outer end of the lever, and pulled down by the man appointed for that purpose. When the ram has been struck off, the speed of the chain must be reduced by partially cutting off the steam until the catch has again entered the chain. Particular attention should be paid to keep the chain and catch well oiled, likewise the bearings of the top and bottom sheaves, and all the working parts of the winch; and when commencing to work, to let the ram go slowly up to the striking-off staples until everything is free, and the working of the winch is well understood. It is always desirable to have clean, fresh water for the boiler, and should it prime, from having salt or dirty water, or from any grease having been left in, and to prevent priming, put in some soda or potash, and when the steam is up blow off a little at the safety-valve.

When there are a great number of piles to be driven in regular order, such as, for instance, in the floor of a graving dock, the Nasmyth machine gives very good results. In the construction of the Brooklyn dock a large number of the piles were driven by a Nasmyth machine, with a ram weighing 8 tons. The fall or stroke was 3 ft., and from sixty to eighty blows a minute were delivered. The Nasmyth hammer was found to drive piles to a much greater depth than the other machines employed on the works, and although the force of its blows is much less than those of the ordinary rams, when falling 30 ft. it produces a much greater effect. With the Nasmyth machine, piles were driven 35 ft. in seven minutes, while with the other machines similar piles require one hour or more to drive them the same distance. Two trial piles were driven with each of these machines, with the following results;—

TABLE IV.—PILE DRIVEN BY THE NASMYTH MACHINE.

The first	4	blows drove it	4	in. at each blow.
„ next	8	„	3½	„
„ „	22	„	3	„
„ „	25	„	2	„
„ „	40	„	1¾	„
„ „	56	„	1½	„
„ „	32	„	1¼	„
„ „	64	„	1⅛	„
„ „	73	„	1	„
„ last	49	„	½	„

This pile was nearly the same size as the other trial pile, and was driven 43 ft. in seven minutes with 373 blows, and was not iron-shod.

TABLE V.—PILE DRIVEN BY A RAM WEIGHING 1 TON, FALLING FROM ½ TO 35 FEET.

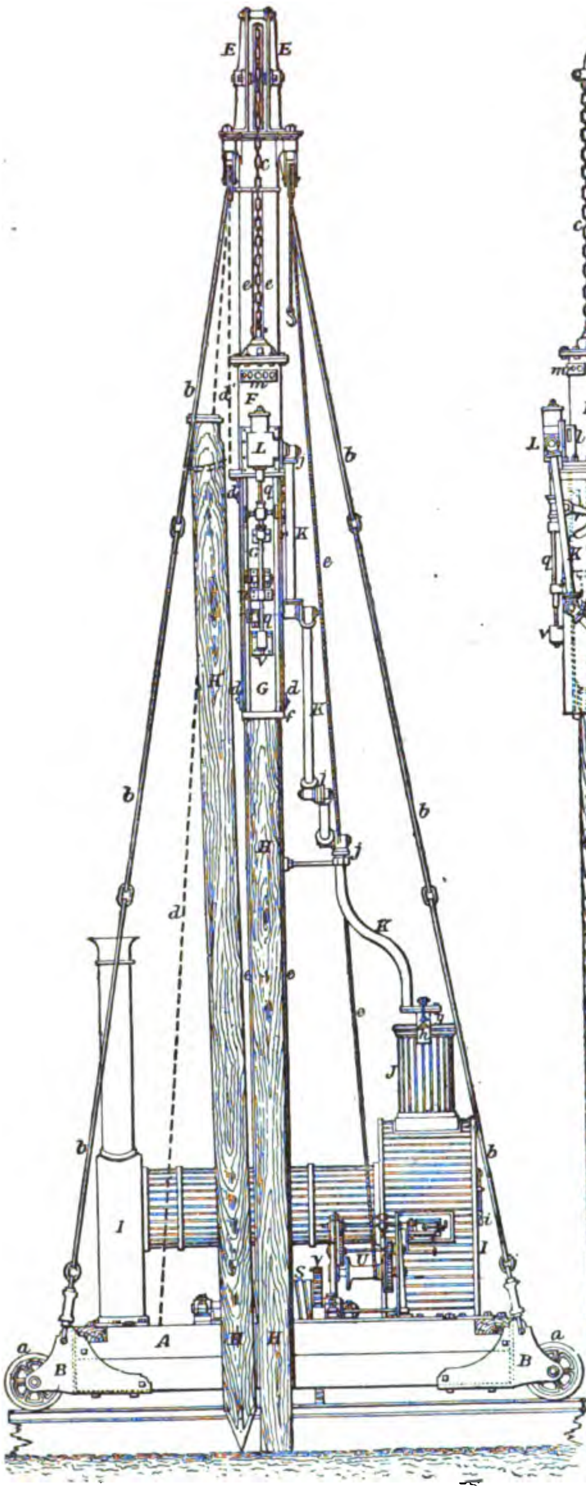
The first	100	blows drove it	a few feet.
„ next	260	„	30 in. in all.
„ „	265	„	from ½ to 1½ in. at each blow.
„ „	110	„	„ 1¼ „

This pile was driven 45 ft. with 735 blows. It was 20 in. in diameter at one end and 14 in. at the other, and was shod with iron. It occupied 166 minutes in the driving, namely, 264 blows in 46 minutes, 265 blows in an hour, and 110 blows in an hour. The rapidity of the action of the Nasmyth hammer is of great advantage. The blows succeeded each other at intervals of a second, and before the material which had been displaced by the vibrations of the preceding blow could settle round the sides of the pile, and therefore nearly the whole force of the blows was employed in displacing the earth near the pile. With the other machines the blows were given at intervals of a minute, by which time the vibrations caused by the preceding blow had ceased, and the semi-fluid material had subsided round the pile, so that a considerable portion of the force of the blows was consumed in overcoming the friction along the sides, thus leaving only a comparatively small part of the force to displace the earth at the bottom of the pile.

Fig. 6324 is a front elevation, and Fig. 6325 a side elevation, of Nasmyth's pile-driver.

The foundation on which the machine is erected consists of a strong wooden platform A A, firmly framed together and strengthened by diagonal timbers and wrought-iron corner pieces, the whole being further secured by cast-iron brackets B, B, at each angle of the platform, in which the locomotive wheels *a*, *a*, are fitted to work upon rails disposed parallel and close to the line of piling on which the machine is destined to operate. The great vertical guide-pole C C, on which the driving apparatus slides, is securely bolted to one side of the platform, the boiler being situated towards the opposite side, to counterbalance the weight of the former, and to afford an abutment for the diagonal timber supports D, D, bound to both by plates of iron and numerous bolts. The entire framework of the machine is also secured by the four adjustable tie-rods *b*, *b*, attached to the four corners of the stage and to the top of the upright. This latter is surmounted by a cast-iron socket-frame supporting the brackets E, E, which carry a chain pulley, over which works the great

6324.



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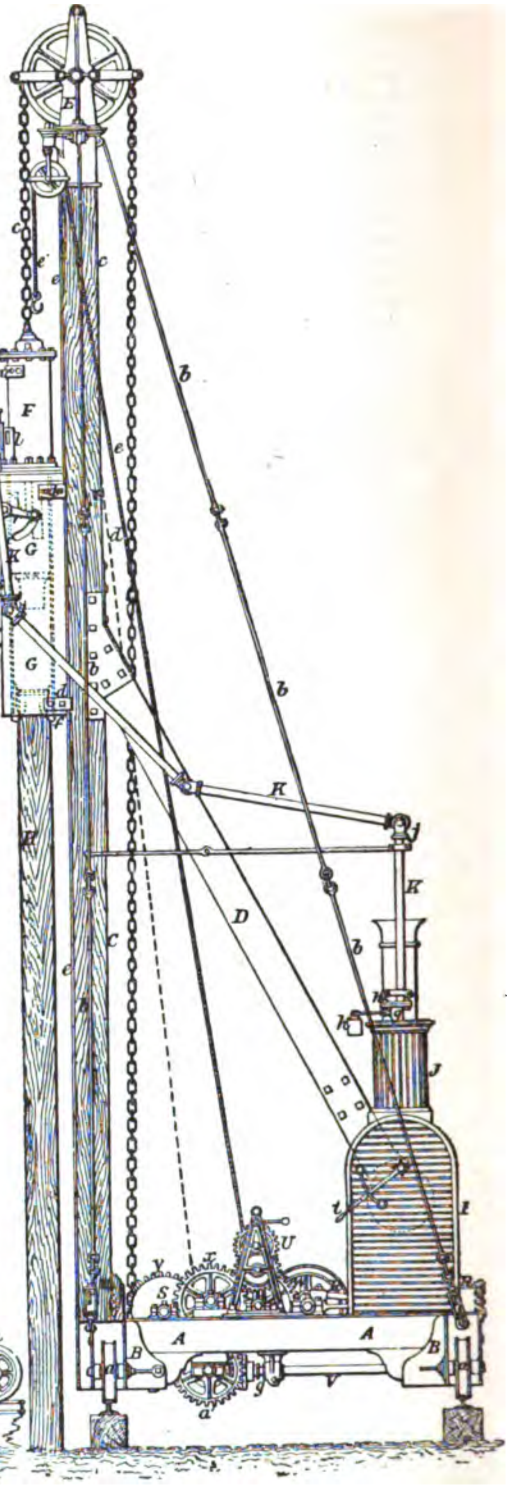

chain *c c*, one end of which is passed round a barrel worked by a small steam-engine, while the other end is attached to, and sustains the weight of, the pile-driving apparatus.

This consists of a steam-cylinder F, with all the necessary appendages. The lower flange of the cylinder is firmly bolted to the pile-case G G, which is a species of rectangular box of a square section, constructed of plates of wrought iron strongly framed together. The interior surfaces of the pile-case serve to guide the hammer-block in its vertical motion, and it is itself guided along the great upright C C, by the pieces *d*, *d*, which are fitted to embrace the projecting slips of iron *e*, *e*, bolted to the front of the upright throughout its entire length. The lower end of the pile-case is open, to admit the head of the pile, and is furnished with cast-iron jaws or resting-pieces *f*, *f*, bolted to its interior surfaces; these are so formed as to rest upon the shoulders of the pile H, which, if we suppose the great chain barrel to be left free to revolve, thus becomes the sole support for the weight of the whole mass of the driving apparatus. By these arrangements, it will be seen that as the pile is, by successive steps, forced into the ground by the action of the hammer, the chain barrel being thrown out of gear with its driving apparatus during the process, the pile-case, with all its appendages, weighing about 3 tons, is left at perfect liberty to bear upon the shoulders of the pile, and follow down along with it, while at the same time, and by the same means, the pile itself is guided into a strictly vertical and true course.

The driving apparatus consists simply of a modification of Nasmyth's steam-hammer, the action of the various parts being in all respects identical, though the whole is movable. The steam necessary for its supply is generated in a boiler Y, the construction of which is very similar to that of the ordinary locomotive engine boiler. The steam-chest T surmounts the fire-box, and is made of sufficient height to prevent the influx of water into the steam-pipes, and the entire boiler and steam-chest are covered externally with a coating of felt, and with strips of wood to prevent the radiation of heat, and to give greater symmetry of appearance. On the cover of the steam-chest is cast a small square box *g*, containing suitable bearings for the safety-valve, which is loaded by a weight and combination of levers *h*, *h*, and for the throttle or shut-off valve, commanded by the lever-handle and rod *i*, *i*. The steam is conveyed from the boiler to the valve-chest of the driving cylinder by a flexible steam-pipe K K, composed of several lengths of wrought-iron tube, connected together by swivel joints of cast iron *j*, *j*. This arrangement admits of the steam-pipe accommodating itself, without any loss of steam from leakage, to every variety of height or distance at which the driving cylinder may be from the boiler, from the commencement of the process, when the apparatus is sitting aloft upon the shoulders of a tall pile, until it has arrived at its lowest position, when the pile has penetrated the soil to the required depth.

The remaining part of the driving apparatus is, as we have before had occasion to remark, identical in the principles of its action, and very similar in the details of its construction, to those of the Nasmyth steam-hammer.

F is the steam-cylinder, within which the power necessary for raising the hammer to the required elevation—3 ft.—is generated.

L the steam valve chest, bolted to the lower side of the cylinder, within which a valve is fitted to work upon a face cast with the cylinder.

The steam, after having accomplished its work, is permitted to escape into the atmosphere by an oblong aperture *l*, formed in the cylinder face; and, to obviate the risk of accident from the piston rising too high, a number of small round holes, *m*, *m*, are formed near the top of the cylinder, so that the steam may blow out into the air when the piston rises above their edges.

Within the cylinder F is the piston, formed of wrought iron, and fitted with a single packing ring, and the piston-rod, having a cylindrical boss or enlargement at its lower extremity, for the purpose of affording means for securing a slightly elastic connection, by hard-wood washers, between the piston-rod and hammer-block.

The hammer-block, consisting of a rectangular mass of cast iron weighing 30 cwt., is adapted to slide freely, but without much play, within the pile-case G G. It is furnished with suitable recesses for the securing of the hammer piston-rod, and for enabling it to rise clear of the cylinder stuffing-box; and at its upper extremity a recess, in the form of a species of inclined plane, is provided, for the purpose of acting upon the valve-lever, so as to permit the escape of the steam after it has raised the hammer to a sufficient height.

The hammer is a cylindrical block of cast iron, formed with a slightly concave face, fitted into the hammer-block, and fastened thereto by a wrought-iron key, which at the same time serves to secure the connection of the piston-rod.

q, the valve-spindle, produced downwards and working in suitable bearings, so as to bring it under the action of the trigger at the termination of the stroke.

r, the valve-lever, working outside of the pile-case, but having a small friction-roller attached to its inner end, and situated so as to come under the action of the inclined plane.

s, the trigger, the function of which is to keep the steam-valve in such a position as to prevent the admission of steam into the cylinder during the descent of the hammer-block.

Beneath the trigger is a parallel bar, against which the latch-lever acts at the termination of the stroke, for the purpose of releasing the valve-spindle from the trigger, in order to allow the steam to be admitted for a fresh stroke.

u, the parallel motion bell-cranks and connecting rod of the disengaging apparatus.

v, a buffer-box for the purpose of restricting the travel of the valve to its proper amount, and of deadening the shocks to which it is subjected.

The power by which the pile-case and its appendages are elevated to the top of the great vertical guide-pole, and the means employed to render the whole machine locomotive, is supplied by a small horizontal steam-engine R, situated opposite to the great upright C, and under the boiler I, from which it derives its supply of steam. The motion of this steam-engine is transferred to the axis of the great chain barrel by means of a train of spur-gearing, calculated to increase the power to the required extent. Two broad plates of wrought iron, extending across the entire platform, and bolted

securely to its timbers, afford a sufficiently firm foundation for the engine, and for the bearings of the various shafts in the train of wheels, which consists of three pairs marked *w*, *x*, and *y*; the

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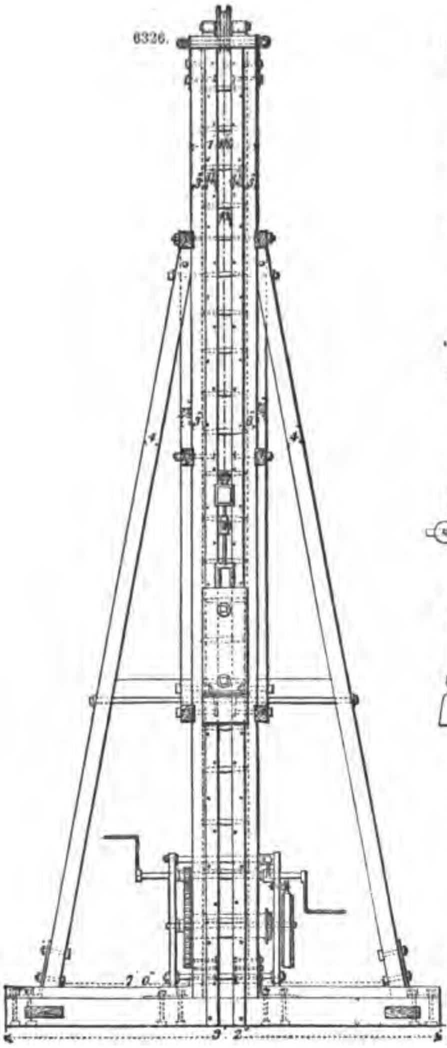

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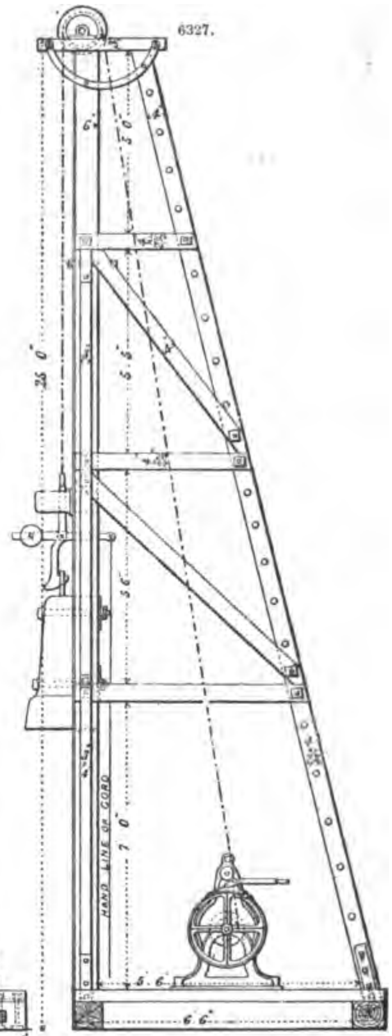
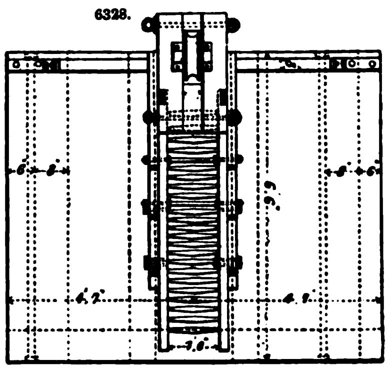


6328.



pinion of the first pair being fixed upon the crank-shaft of the engine, and the wheel of the last upon the axis of the chain barrel. The pinion *y* is fitted to slide longitudinally upon its shaft by means of a sunk feather, and is commanded by a lever-handle, so as to enable the attendant in charge of the machine to throw it out of gear with the wheel upon the chain-barrel shaft, when the latter is to be left free to revolve during the driving of the pile. The wheel *x*, upon the third motion shaft, gears with a similar wheel *a'*, fixed upon a cross shaft working in bearings under the platform, and serving to impart motion at once to a small chain barrel for hoisting the piles and to the locomotive gear. A clutch, or coupling, sliding upon the shaft, enables the attendant to throw the small chain barrel into gear with the driving apparatus, or disengage it at pleasure; the remaining details of this part of the process will be fully understood by reference to Fig. 6324, where a pile H' is shown suspended from the chain *d'*, ready to come under the action of the driving machinery. To adjust the pile-case over the head of the pile at the commencement of the driving, it is necessary that one or two men should

be raised to the summit of the machine. A rope e', passed over a pulley at the top of the great upright, and wound round the barrel of a winch U, serves to accomplish this object.

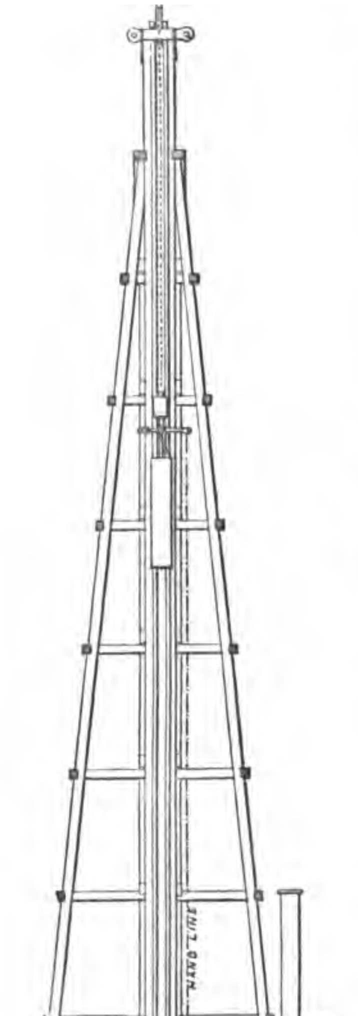
The locomotive gear is exceedingly simple, and will be at once understood by referring to Figs. 6324, 6325. A bevel-wheel fixed to the outer end of the shaft, supporting the wheel a', gears with another of equal diameter, working loose upon the shaft V, to which a pair of the locomotive wheels a, a, are fixed. When it is required to move the platform with its superincumbent machinery along the line of rails, a sliding clutch g' is thrown into gear with the last-mentioned bevel-wheel, and is disengaged when the machine has arrived at the desired position.

Action of the Machine.—The pile having been raised by means of the hoisting apparatus, and its point having been set into the proper position, the pile-case G G, with its attached machinery, is lowered down over the head, by reversing the small engine R, so that the jaws f, f, rest upon the shoulders of the pile, which sinks down into the ground by the effect of the superincumbent weight, till it has reached soil sufficiently firm to support it; this is indicated by the chain $c\,c$ becoming slack. The pinion y is then thrown out of gear, and the steam is admitted into the driving cylinder F by turning the handle i. The hammer-block is by this means raised till its inclined plane, coming in contact with the end of the valve-lever r, causes the valve to discharge the steam from the under side of the piston. The steam which had served to raise the hammer is thus allowed to blow out into the air, and the hammer descends and discharges its momentum in the form of an energetic blow upon the head of the pile. During the descent of the hammer-block, the steam-valve is retained in its proper position by the action of the trigger s, but by the effect of the concussion upon the head of the pile, the valve-spindle is released from contact with the trigger, and the steam-valve allows steam to act freely under the piston, for the purpose of again raising the hammer.

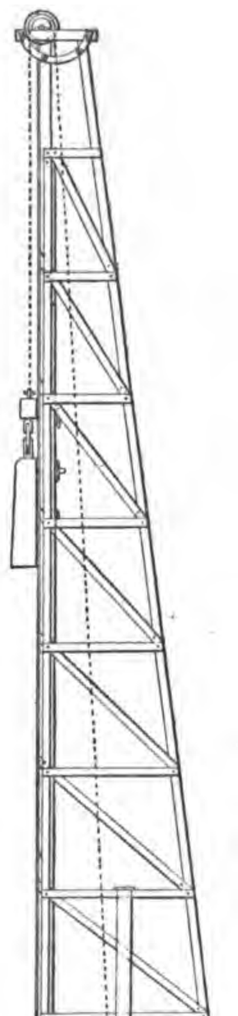
A very good machine by Appleby Brothers, of London, is shown in Figs. 6326 to 6328, which represent a hand-machine in side elevation, front elevation, and plan. A somewhat similar example by the same makers adapted for steam power is shown in Figs. 6329 to 6331.

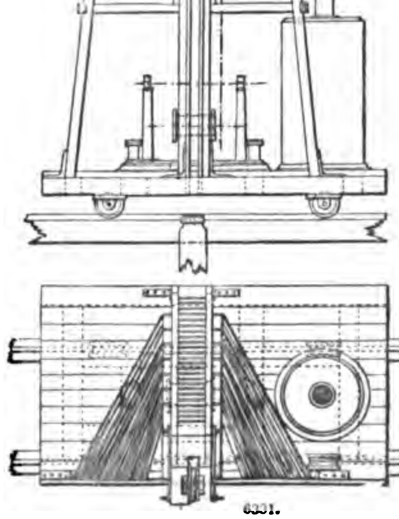
The hand pile-driver, Figs. 6326, 6328, is usually 30 to 40 ft.

6329.



6330.





6331.

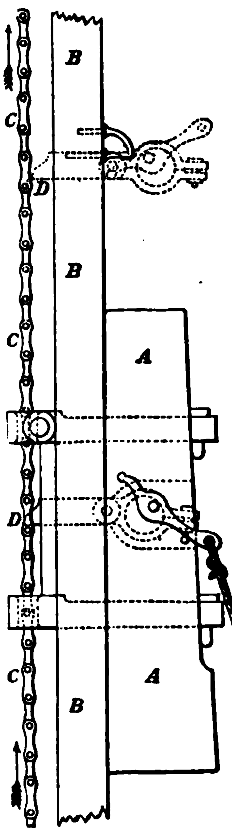
high, and consists of a pair of timber leaders 6 × 8 placed on a square frame about 4 in. apart, the front and back being plated with wrought iron; the top of the leaders carry a cast-iron sheave working freely in a pair of carriages; side struts and back struts are braced to the leaders, and wrought-iron knees render the whole a stiff and rigid framing. The cast-iron ram for a machine of this kind is from 10 to 18 cwt., and has a feather cast on the back to fit loosely into the groove formed by the two leaders, two bolts and plates passing through it to prevent it from falling out of its guides; a strong staple of square iron is cast into the top; the ram should not exceed 12 in. square, as it frequently happens that one pile will go much lower than another, and if the ram is larger than the pits it does not follow down between those on each side. The crab-winch is of single purchase with long and strong handles, so that four or five men can work at them; the attachment of the chain to the ram is made by a catch lever or nipper; this is attached to the end of the chain together with a cast-iron balance-weight guided on the leaders in a similar manner to the ram, and which serves to overhaul the chain after a blow has been made. The method of working the machine is as follows;—the ram is attached to the chain by the nipper, engaging the staple on the ram, and the men at the winch raise the monkey any desired height, when the gauger, by means of a hand-line and lever, releases the ram, which falls on the pile-head, the hand-shaft of the winch is thrown out of gear, and the balance-weight brings down the chain to the ram for the next blow; the descent of the balance-weight and chain is regulated by a break on the crab under control of one of the men.

The steam pile-driving machine, Figs. 6329 to 6331, is a simple adaptation to perform the operation by steam. The frame is the same in construction as that last described, but is made much stronger, a double-cylinder steam-winch taking the place of the hand-winch; the barrel is loose on its shaft, but can be made fast to it by a toothed clutch and lever, the same lever actuating a brake on the barrel to control the ascent of the chain and balance-weight; the boiler can be placed on the same frame, or in some cases a number of engines are worked from one boiler, which is placed in any convenient position, the pipes being laid as far as practicable in iron, with a short piece of flexible steam hose connecting the pipe and crab so as to admit of the pile-driver being moved a considerable distance without altering the connections; the engines run continuously in one direction, and when the barrel-clutch is thrown into gear, the ram ascends until released by coming in contact with a stop, or by the hand-line which is attached to the nipper; immediately this is done the operator at the winch throws out the clutch, and the balance-weight and nipper overhauls the chain, and from the construction of the nipper attaches itself to the staple of the ram ready for the next lift. Ten to twelve blows a minute can thus be easily made.

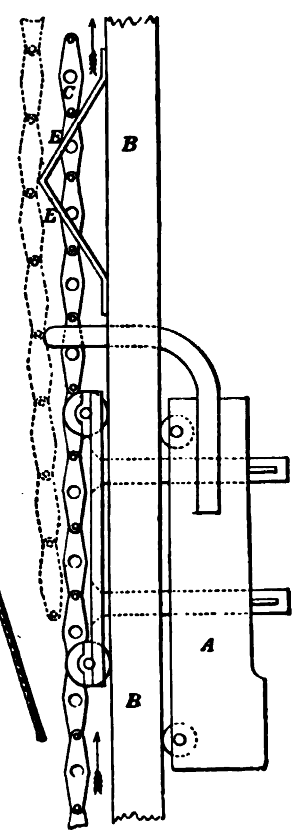
The whole machine is often mounted on a set of flanged wheels and axles for moving along a tramway. The frames are so constructed as to throw the leaders out of the perpendicular when it is required to drive the piles on a batter.

The steam pile-driver, Figs. 6332 to 6335, belongs to the class of endless-chain pile-drivers, which have come into use for large works both in this country and abroad, being found to possess an important practical advantage in the continuous motion of the chain running always in the same direction. In consequence of this, the engine never requires to be stopped or reversed during the performance of the work, nor are any reversing clutches required for reversing the motion of the crab winding the chain.

6332.



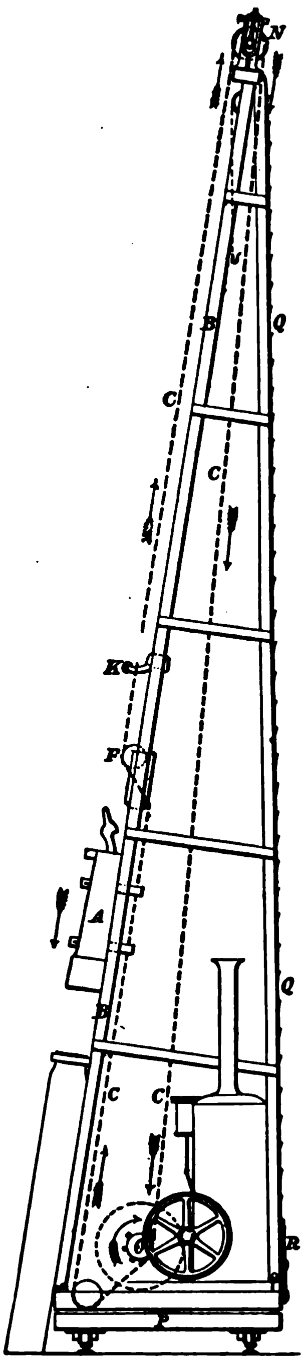
6333.



The chief improvement aimed at in this pile-driver, states Peter B. Eassie in the Proceedings Inst. M. E., has been to lift the ram by its centre of gravity, and thus reduce the friction on the front and back of the leaders. In the pile-drivers hitherto in use the ordinary mode of attachment of the lifting chain to the ram has been shown as in Figs. 6332, 6333, where the attachment of the ram A to the chain C as it the back of the leaders B; and the ram is released either by withdrawing the catch D, as shown in Fig. 6332, or by throwing out the chain from the catch by an inclined stop E, as shown in Fig. 6333. Although the effect of the blow, when the ram is released, is the same as with any other mode of attachment, the friction in lifting is excessive, in consequence of the nipping action at front and back of the leaders, arising from the canting of the ram against the leaders; and this binding

effect increases in intensity the greater the distance of the point of attachment from the line of the centre of gravity of the ram. This friction has been ascertained by experiment to amount to

6334.



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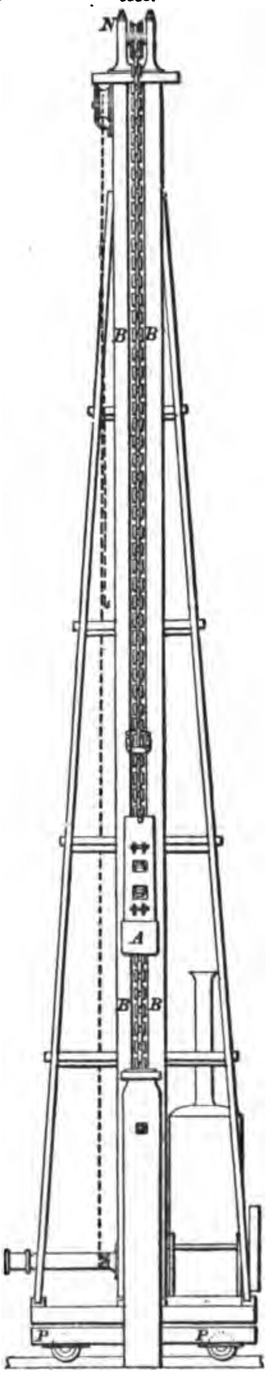

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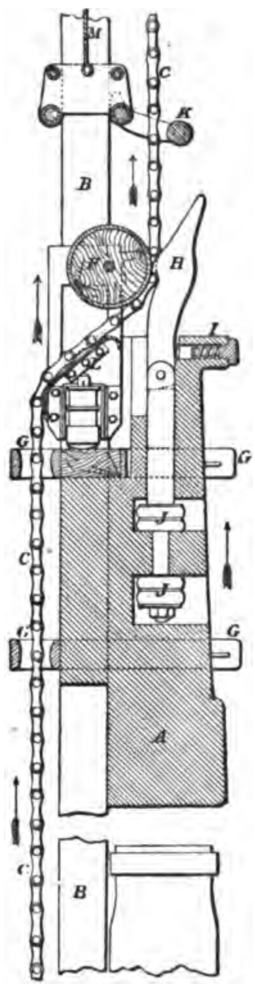

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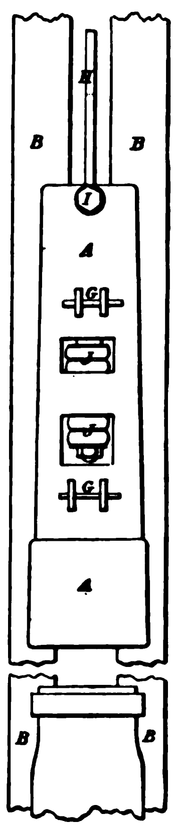
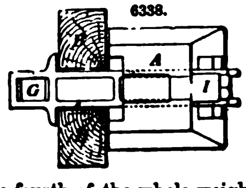


6338.



nearly one-fourth of the whole weight of the ram, so that in lifting a ram of 1 ton weight the force required to be exerted amounts to 1¼ ton, in addition to that required to overcome the inertia of the machinery.

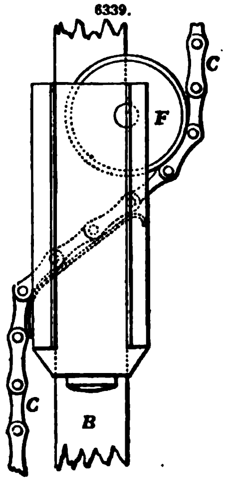
Fig. 6334 is a side elevation of the pile-driver, driving a raking pile; and Fig. 6335 shows a front elevation of the machine.

The ram A, shown to a larger scale in Figs. 6336 to 6338, weighing from 15 to 30 cwt., slides freely between the leaders B, B, being kept in position by the two clamp-bolts G, G, which fit into slots in the ram, and have eyes at the back for the lifting chain C to pass through. The steel hook H, for lifting the ram, is jointed on the top of a rod passing through the centre of gravity of

the ram; and is constantly pressed inwards by a small spiral spring I, so as to engage in the links of the lifting chain C. The attachment of the lifting rod to the ram is made with springs J, J, in order to ease the sudden strain occasioned by the weight of the ram being thrown suddenly upon the chain. India-rubber springs are found to serve this purpose the best, steel volute springs having been found liable to break, as the space through which the lifting rod has to yield amounts sometimes to as much as 2 in. when the chain is driven at its greatest speed.

The lifting chain C, passing up through the eye-bolts G at the back of the ram, Fig. 6336, is brought forwards to the front of the leaders B and into the line of the centre of gravity of the ram by means of the follower F, which consists of a light iron frame carrying the roller F, and sliding freely between the two leaders B, B, as shown to a larger scale in Figs. 6339 to 6341. During the ascent of the ram, the follower rests upon the top of it, and is carried up with it, and as soon as the lifting hook H has been disengaged from the chain by the striker-off K, Figs. 6334 and 6336, the ram falls and gives the blow, and the follower runs down after it as rapidly as the friction of the chain in passing under the roller F will allow. The slight retardation thus produced in the descent of the follower is sufficient to allow time for the rebound of the ram after striking the blow to cease, before the follower overtakes it; and an india-rubber buffer-spring fixed in the bottom of the follower reduces the shock of the follower falling upon the ram. The roller F of the follower is made of wood hooped with iron, and revolves freely between the side plates of the follower; while the sloping fender-plate L prevents the slack of the chain from accumulating at the follower. The follower is guided between the leaders B, B, by four strips of angle-iron riveted on the side plates, as shown in the plan, Fig. 6341; and as soon as the follower overtakes the ram, it brings the lifting chain within reach of the hook H, which instantly engages in the chain again, and the ram is raised as before.

6339.



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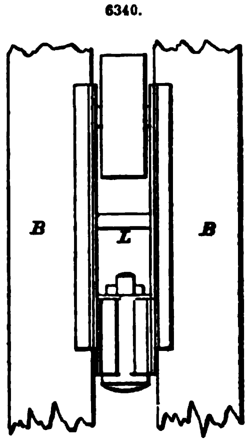

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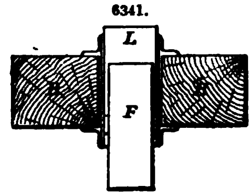
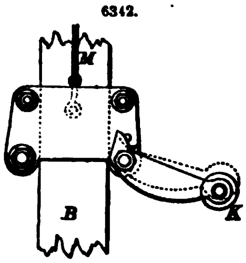
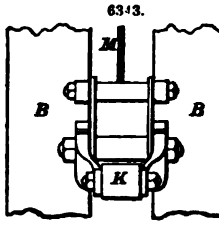


6342.



6343.



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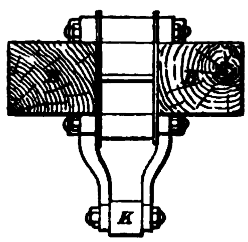

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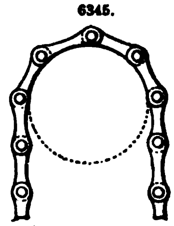


6346.

The striker-off, for disengaging the ram from the lifting chain, is shown in Figs. 6342 to 6344, and consists of an iron framing somewhat similar to the follower, on the front of which is a pair of bell-crank levers carrying a roller. When the engaging hook H of the ram comes in contact with this roller, it first raises the levers and gives them a nipping action upon the leaders B, by which the striker-off is held tight in its place and prevented from being lifted by the ascent of the hook; and then the roller K, bearing against the tapered extremity of the hook, disengages the hook from the lifting chain C, and the ram falls freely. The height of fall is regulated simply by raising or lowering the striker-off by the cord M, which passes over a pulley on the top of the leaders, the end of the cord being secured within reach of the engine-man.

The endless pitch-chain, by which the ram is lifted, is shown in Figs. 6345, 6346, and consists of double and single links alternately; the lifting hook of the ram engaging in the spaces left between the double links. The links are curved on the edges to fit the rollers over which the chain runs. The pins are of steel, and the middle portion passing through the centre link is made of rather larger diameter than the two ends, leaving a shoulder against which the outside links are riveted on tight, so that the centre link can work freely on the pin. At about every 8 ft. in length

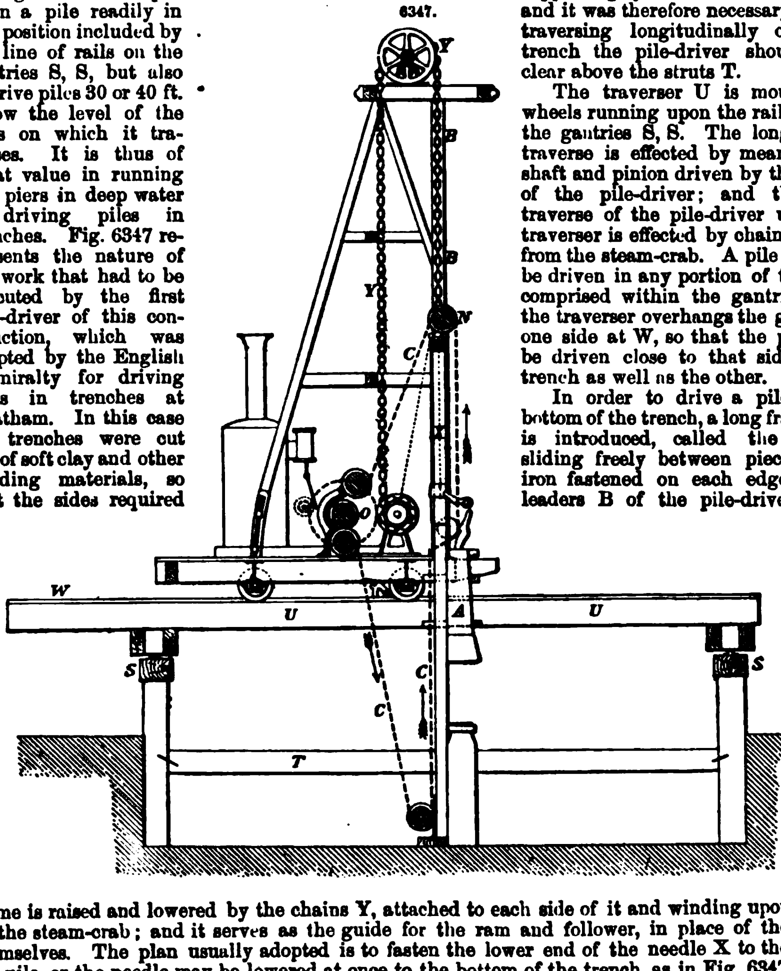
of the chain a screw-pin is used instead of a rivet, for facility in putting the chain together, or for taking it to pieces in case of repairs.

During the working of the pile-driver, the chain is kept constantly running in an upward direction in front of the leaders for lifting the ram. It passes over the pulley N, Figs. 6334, 6335, at the top of the leaders, and thence down to the pitched wheel O on the main shaft of the crab; then under a guide-roller in the platform of the machine, and up behind the leaders to the follower F, by which it is again brought in front of the leaders above the ram A. The chain is tightened or slackened as required by means of adjusting screws regulating the position of the top pulley N. In practice it is kept slack enough to allow of the follower F descending readily by its own weight after each fall of the ram.

The whole machine is carried on a platform P, Figs. 6334, 6335, having at each corner double-flanged wheels, so that the pile-driver can be moved easily in either direction on rails laid down for the purpose. On this lower platform is carried an upper one, turning upon a centre-pin like an ordinary turn-table, so as to allow the pile-driver to be faced to any of the four sides of the machine. On the upper platform are hinged the leaders B and side stays, connected by framing to the back ladder Q, at the foot of which there is a strong adjusting screw and guide R, allowing the pile-driver to be set to any inclination up to 1 in 6 when required, in order to drive raking piles, as shown in Fig. 6334. The boiler is an upright one, and the engine is placed vertically with the cylinder inverted, working down upon the crank-shaft, on which is the pinion driving the crab O. The large shaft of the crab carries a double clutch-box, having on one side the chain-drum for lifting the pile, and on the other side the pitched wheel driving the endless chain C which raises the ram. A brake is provided, so that either the pile or the ram can be lowered gently at any time.

The pile-driver, Fig. 6347, is called a telescopic pile-driver, being designed not only to command a large area and put down a pile readily in any position included by the line of rails on the gantries S, S, but also to drive piles 30 or 40 ft. below the level of the rails on which it traverses. It is thus of great value in running out piers in deep water or driving piles in trenches. Fig. 6347 represents the nature of the work that had to be executed by the first pile-driver of this construction, which was adopted by the English Admiralty for driving piles in trenches at Chatham. In this case the trenches were cut out of soft clay and other yielding materials, so that the sides required supporting by means of the struts T, T; and it was therefore necessary that in traversing longitudinally over the trench the pile-driver should pass clear above the struts T.

6347.



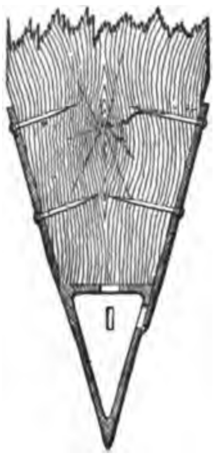
The traverser U is mounted on wheels running upon the rails laid on the gantries S, S. The longitudinal traverse is effected by means of the shaft and pinion driven by the engine of the pile-driver; and the cross traverse of the pile-driver upon the traverser is effected by chain gearing from the steam-crab. A pile can then be driven in any portion of the space comprised within the gantries; and the traverser overhangs the gantry on one side at W, so that the piles may be driven close to that side of the trench as well as the other.

In order to drive a pile to the bottom of the trench, a long frame X X is introduced, called the needle, sliding freely between pieces of T iron fastened on each edge of the leaders B of the pile-driver. This frame is raised and lowered by the chains Y, attached to each side of it and winding upon a drum on the steam-crab; and it serves as the guide for the ram and follower, in place of the leaders themselves. The plan usually adopted is to fasten the lower end of the needle X to the head of the pile, or the needle may be lowered at once to the bottom of the trench, as in Fig. 6347. After the pile has been driven, the needle is raised clear of the struts T or level with the rails, and the machine can then be traversed in any direction longitudinally or transversely, the whole of the movements and the lifting of the needle being effected by the steam power on the platform of

the pile-driver. The leaders and side stays of the machine are hinged, so that they can be adjusted for driving raking piles with the needle, with the same facility as in the construction of pile-driver previously described. The endless pitch-chain C is connected solely to the needle X and steam-crab O, and as it never requires to be stretched perfectly taut, it is always ready for immediate use, whether the needle is raised to the top or lowered to the bottom of the trench.

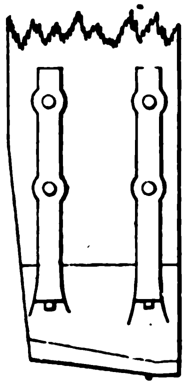
The cast-iron pile shoes, Figs. 6348 to 6356, were designed by Peter B. Eassie for the purpose of

6348.



6351.

6352.



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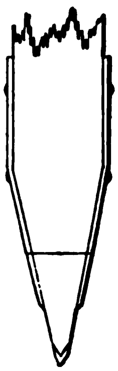

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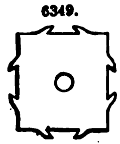

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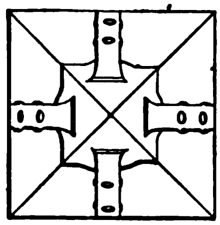

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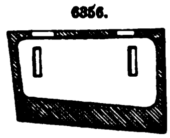

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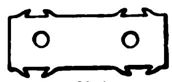


6354.

affording a broad base to the wood of the pile itself, and also with a view to economy of space in packing for export. The shoe shown in Figs. 6348 to 6350 is for an ordinary square pile, and that in Figs. 6352 to 6356 for a sheet pile; consisting in each case of a hollow casting forming the toe of the pile, with dovetailed recesses cast on for the attachment of the wrought-iron straps, Fig. 6351, which after being adjusted are fastened to the pile by spikes in the ordinary manner. All the dovetails and the ends of the straps being made alike, they are readily attached, and are found to take up considerably less room in stowage than many other constructions; while owing to there being no holes at the point of attachment. the straps can be made small in size. Before being used these hollow shoes are sometimes filled up with cement or some other material easily obtained at the site of the work.

The accompanying Table on the authority of P. B. Eassie gives the particulars of half-a-day's work with one of the telescopic pile-drivers employed at Cardiff Docks. Some difficulty was experienced in this case in getting at the exact height of fall of the ram, as the machine was at work upon gantries, driving piles in water; but the fall was ascertained to be on an average about 10 ft. The last forty or fifty blows were given with a fall of 14 ft., causing the pile to go down from $\frac{1}{8}$ in. to $\frac{3}{16}$ in. a blow. The weight of the ram was $21\frac{1}{2}$ cwt.; and the size of the piles was 13 in. square, and their average length 46 ft.

TABLE VI.—TELESCOPIC PILE-DRIVER AT CARDIFF DOCKS.

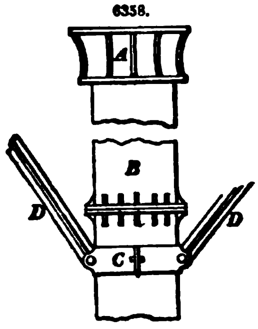
	Length driven.	Total No. of Blows.	Time occupied.			Mean Steam-pressure.
			Setting.	Driving.	Total.	
	feet.	No.	mins.	mins.	hrs. mins.	lbs.
Pile No. 1	35	113	40	40	1 28	42
„ No. 2	27	140	30	35	1 18	45
„ No. 3	32	130	50	34	1 50	43
Average	31	128	40	36	1 32	43

The average result of the observations made upon the driving of these three piles in succession was that the number of blows required to drive each pile to a depth of 31 ft. was 128 blows, and the time occupied in actually driving was 36 minutes; the total time spent in driving the three piles, including all delays, was 4½ hours.

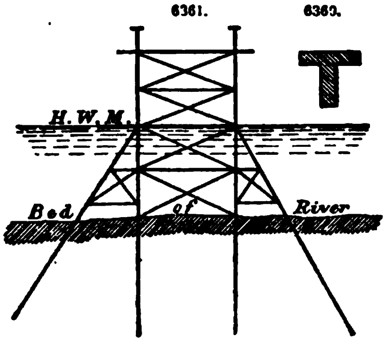
Screw Piles.—A screw pile differs from an ordinary pile of timber, or cast or wrought iron, by being furnished at the lower extremity with a screw or spiral. The screw is of particular construction, as it is provided with only two or three blades, which are of different diameter. The upper of these has the greatest resistance to contend with, and is therefore of a larger diameter than the others, sometimes reaching the dimension of 4 ft. The pile being adjusted in either a vertical or inclined plane as required, a rotary movement is imparted to the upper extremity, and the penetration commences. One of the chief merits in thus obtaining a foundation is that the pile does not dislodge the earth near and round about it. Thus fixed in position, the pile can be used either as a mooring post, or as a portion of a pier upon which to erect a bridge, jetty, or other superstructure. The screws are either cylindrical or conical, of cast or wrought iron, and the piles may be also of either material, or of timber. According to the nature and consistency of the ground to be penetrated, so must the shape and size of the screw be. If the earth is of a loose, friable, easily penetrable character, a cylindrically-formed screw will answer for the purpose; but if it is of a compact, tenacious description it becomes necessary to use a screw in the shape of a cone. No screw, whatever may be its form and powers of boring, will penetrate into rock, but the principle has been successfully applied in instances where the foundation was a bed of coral. As a rule, a capstan worked by manual labour is found sufficient to drive a screw pile. One of these machines with eight bars about 20 ft. in length, each manned by five or six labourers, has been found capable of getting down a pile 4 ft. in diameter, to a depth of 15 ft. in an hour and a half, in ground composed of sand, clay, and loose rock of a schistose nature. The conditions being the same, a period of two hours was sufficient to sink a screw pile to a depth of 21 ft. In cases where it is not possible to employ the leverage of capstan-bars, the head of the capstan is furnished with a wheel which can be worked by an endless rope or chain set in motion by a gang of men. Where the earth is very dry, screw piles can often be got down by very simple means. It sometimes suffices to fix to the upper end of the pile a rod with an eye in it to attach a short iron lever, and screw the pile down. This arrangement will only be available for short depths.

The ordinary screw-pile is represented in elevation in Fig. 6357, which shows the end portion

6358.

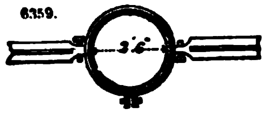


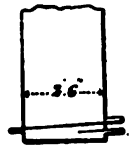
6361.



6360.

6359.





6357.

cast upon Mitchell's principle, to which the upper lengths are bolted. A very usual dimension for the size of the pile is 2 ft. 6 in. in diameter, but any size may be adopted, provided it is borne in mind that the difficulty in getting it down varies directly as the area of the flange. Besides, if a certain dimension be exceeded, the pile virtually ceases to bear that character, and becomes transformed into a cylinder, which constitutes in itself a different system of foundation. The upper lengths of the pile are formed slightly different from that carrying the screw, and are represented in elevation in Fig. 6358, and in plan in Fig. 6359. A is the cap which, after casting, is turned in a lathe to ensure a true bed for the girder to rest upon, and also to give a finish to the appearance of the pile. The average length of each separate casting is about 9 ft., some shorter lengths being always cast in addition to bring the pile up to the proper level, as it might in some situations be nearly impossible to get it down for another length of 9 ft., supposing the preceding length was below the proper level. Owing to the great length of the piles in comparison with their lateral dimensions, they require to be strongly braced together by diagonal ties and struts, so that they should form a complete framework of rigidity and lateral stiffness. This is accomplished by the braces D, which are of the section shown in Fig. 6360. They are connected to the piles by means of the wrought-iron rings C, which are fixed round their circumference, and are either riveted or bolted to the extremities of the braces. This arrangement is shown in plan in Fig. 6359. Flanges are cast upon the ends of the separate 9-ft. lengths, and they are thus bolted together, as at B in Fig. 6358. Of all the applications made of the principle of screw piling, the most extensive is that carried out upon the Bombay, Baroda, and Central India Railway. Upwards of six miles of bridges, in the aggregate, have been erected by their aid throughout the line. It may be

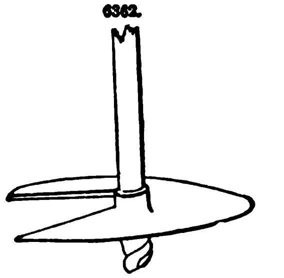
mentioned that the velocity of the floods in rivers similar to the Jumna and Nerbudda reached a maximum of ten miles an hour, with an average depth of fully 40 ft. The portion of the pile shown in Fig. 6358 is that which stands above the level of low water. That below that level, and also the part penetrating the bed of the river, has the flanges, by which the several lengths are bolted together, cast upon the interior instead of the exterior of the circumference, so as to present no impediment to the free descent of the pile through the ground. We have already mentioned that the diameter of the pile should not exceed certain limits, and it is equally apparent that it should also possess a dimension sufficiently large to allow of a man getting inside and bolting the different lengths together. Wherever the current acts in contrary directions, the piles must be strengthened by the addition of others, fixed in an oblique direction and tied to them at intervals by diagonal bracing. The general arrangement of this description of strutting is shown in the skeleton elevation in Fig. 6361, and it must be borne in mind that, in consequence of the variable nature of the strains, all the braces must be made of a section suitable for resisting both tension and compression. This is an important point to be attended to, for a diagonal bar that would solely resist a considerable strain of tension would be of little or no use if that strain were changed to one of the opposite character.

Screw piles are well adapted for obtaining a foundation in situations similar to that of a sand-bank, and where the usual means would be unavailable. They have also been much used in the erection of lighthouses.

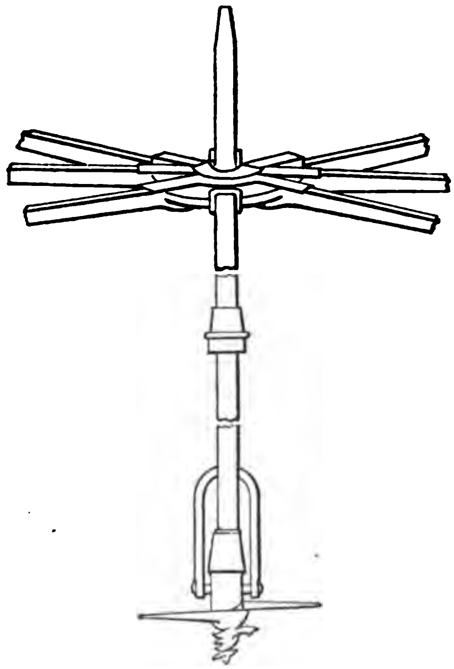
A distinction must be drawn between screw piles, which we have just described, and which are known as disc piles. The latter are not actually screwed into the ground, but the earth is loosened below them, and an alternating motion being imparted to them, they gradually sink down. They are particularly adapted for getting good foundations in sand, which is loosened by forcing water or other fluid under a strong pressure into it, until it permits of the pile descending to a hard bottom. The disc pile has been successfully applied in several sandy localities by Brunlees, who was the first to introduce this peculiar method of sinking them.

The proper area of the screw should be determined by the nature of the ground into which it is inserted, which must be ascertained by experiment. The sizes used have exceeded 4 ft. in diameter, but the dimensions may be strictly said to be limited only by the power available for forcing them into the ground. The screw pile has been extensively used for moorings, and one of the early examples designed by Mitchell is shown in Fig. 6362. It was designed to hold the buoy-

6362.



6363.



chain down. Before the mooring can be displaced by any direct force, a large mass of earth must be also displaced. The mass of earth thus disturbed is in the form of the frustum of a cone inverted, that is, with its base at the surface, the breadth of the base being in proportion to the tenacity of the ground. In the case of moorings, the base is subjected to a pressure of a cylinder of water equal to its diameter, the axis of which is its depth, and the water again bears the weight of a column of air of the diameter of the cylinder. The depth in the ground to which screw-pile moorings have been sunk varies from 8 to 18 ft. The former depth is sufficient where the soil is of a firm and unyielding description, and the latter depth is enough in a weak bottom.

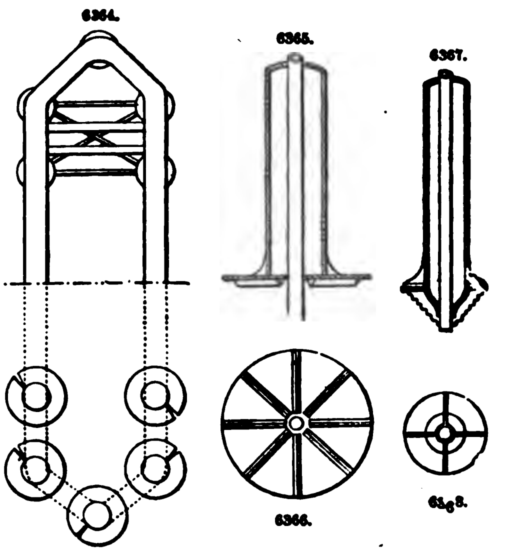
In fixing these screw-pile moorings, barges, lighters, pontoons, and other similar means have been at different times employed. Two such vessels are lashed broadside to each other with a certain space between them, and moored over the desired spot. The screw-mooring is then lowered with the chain attached from the centre of the stage to the level of the water, and as it descends to the bottom, the lengths of the apparatus for screwing it into the ground are successively connected. This apparatus, represented in Fig. 6363, consists of a strong wrought-iron shaft in lengths of 10 ft. or 12 ft. each, connected with each other by key-joints or couplings, the lower end having a square socket to fit the head of the centre pin or axis of the mooring. When the centre-pin rests on the bottom, a capstan is firmly keyed upon the shaft at a convenient height. The men then shift the capstan-bars, and apply their power while travelling round upon the stage,

the capstan being lifted and again fixed as the mooring is screwed into the ground. The operation is continued until the men can no longer move the shaft round, or until it is considered to be screwed down to a sufficient depth. The instrument used in trying the nature of the ground was also employed in testing its holding power. It consisted of a jointed rod 30 ft. in length and 1¼ in. in diameter, having at the end a spiral flange of 6 in. in diameter. It was rotated by means of cross levers keyed upon the boring rod. Upon these levers, when the screw was sunk to the depth of 27 ft., a few boards were laid, forming a platform sufficiently large to hold twelve men. A bar was then driven into the bank at some distance, its top being brought to the same level as that of the boring rod. Twelve men were then placed upon the platform to ascertain if their weight, together with that of the apparatus—in all, about 1 ton—sufficed to depress the screw. After some time the men were removed, and the level was again applied, but nc sensible depression of the screw could be observed. The inference to be drawn from this experiment is, that if a screw pile of 6 in. diameter can support a weight of 1 ton, a screw of 4 ft. in diameter will support 64 tons, since the area of their surfaces is as the square of 1 to 8.

In putting up a lighthouse on the coast of Arklow, in Ireland, where the site was unprotected, with an open sea of seventy miles in front, and a great surf of a considerable force incessantly beating on the shore, it was found impossible to use barges or any floating bodies in the construction of the works. As a steady footing for the men is to a certain extent essential, it was indispensable that the screwing down of the piles should be effected from the work itself. The method of construction was very cheap and simple. The piles were to be placed 17 ft. apart in a direct line outwards. A projecting stage was therefore rigged up extending that distance forward, with the other end temporarily supported by the solid part of the pier. The screw pile was then run forwards upon rollers, lifted by tackle, and placed vertically in the situation it was intended to occupy. A wheel 32 ft. in diameter, formed of capstan-bars lashed together at their ends, with a deeply-grooved end to each, was keyed upon the body of the pile, and an endless rope band was passed around it, and held in tension round a smaller grooved pulley fixed about 150 ft. back towards the shore. The tendency to pull the pile out of the vertical line was resisted by a guide-pole with a grooved pulley at its extremity, which pressed against the shore side of the pile.

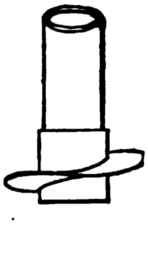
These preparations having been made, a number of men by hauling in the endless band gave a rotary motion to the large wheel, and screwed the pile down to its place with ease. The same operation was repeated until the piles were all down. The bottom into which the piles were inserted consisted of an average depth of about 8 ft. of sand and gravel upon a firm blue clay. Screws of 2 ft. diameter were sufficient, with wrought-iron piles of 5 in. in diameter inserted in the ground to a depth varying from 12 to 15 ft. Screw piles can be got down easily to a depth of 15 ft. into sand in an hour and a half, whereas ordinary timber piles can scarcely be got down to a depth of 12 ft. with all precaution possible in the way of driving. It is stated that the screws penetrate clay with facility. Sand generally gives trouble, especially if there happen to be too many stones in it, but nearly every description of strata has been penetrated by them with the exception of absolute rock. By a modification of the screw it might be made capable of penetrating soft chalk, in which it would find a very good holding. Wrought-iron piles with large screws on them have been got down in sand to a depth of 19 ft. without any very great difficulty being encountered.

Instead of relying upon the supporting power derived from the extent of the frictional surface, a direct-bearing surface may be obtained by the use of the screw and disc pile. Brunlees, instead of a single cylinder, employed in the Eau Brink Viaduct, near Lynn, for spans over 600 ft. a cluster of piles, as represented in Fig. 6364, varying in diameter according to the span. Those shown in Fig. 6364 were 18 in. in diameter, and the screw had a diameter of 3 ft. 6 in. The spans were 111 ft. The bearing surface for each pile was 8·3 sq. ft., or for five, the number under each girder 41·5 sq. ft. The metal in the piles, which were five in number, was equal to that of a cylinder of 4 ft. 4 in. in diameter, or a base of 14·2 sq. ft. By this plan three times the bearing is obtained with the same amount of metal, without taking into account the concrete or masonry, which is needed to protect a cylinder, none of which is required in the piles. The form of the piles must be varied to suit the strata it is intended to penetrate. For fine sands, such as were met with in piling for the Morecambe Bay viaducts and Southport pier, the disc form shown in Figs. 6365, 6366, was used. At the former work the piles were sunk by force-pumps, worked by a two-horse steam-engine, and at the latter by the head of water on the main pipes of the town supply. In both these instances the force of water removed the sand from under the disc, and the piles were gradually lowered as the sand was forced upwards. In the extension of Southport pier, the form shown in Figs. 6367, 6368, was successfully employed. The serrated edges or ribs were introduced as a

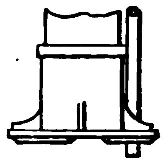


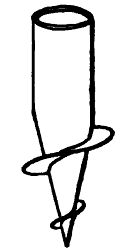
substitute for the cutters shown in Fig. 6364, in order to get through the hard bands of deposit very frequently met with in the sands. These piles were sunk by the aid of two ordinary fire-engines. Brunlees used the corkscrew form shown in Fig. 6369 for hard gravel, shale, and soft rock, which were met with in sinking the piers in the river Mersey. In alluvial deposits, both at home and abroad, the form represented in Fig. 6370, which is that of the ordinary bladed screw pile, was adopted. Out of seventeen river bridges in Brazil, fifteen of them were supported on piles of this shape. In one instance they were employed for a bridge of ten spans, in a depth of water from 35 to 40 ft.

6370.



6371.





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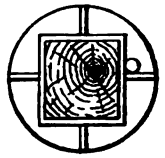


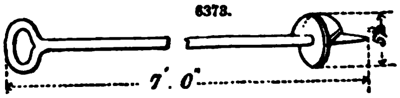
6372.

Brunlees has used over 3000 of the various kinds of piles shown in Figs. 6364 to 6372. He considers that for iron viaducts there are no foundations so weak that piles might not be adapted to them, provided only that the spans are kept within moderate limits, and the piles numerous and of moderate size, so as to diffuse the load as much as possible. For pure sand the disc pile is to be preferred, but in other situations Mitchell's screw pile will be found generally useful. Brick viaducts were screwed into position from a fixed staging in the usual manner. A disc was clamped tightly to the pile and capstan-bars attached to it. The power was applied by two double-purchase crabs, ropes being passed round the capstan-bars in connection with these crabs. Six men worked at each crab, four in winding and two hauling in the slack of the rope. The stratum penetrated in two of the piers had a thickness of 7 ft. of clay and marl, 2 ft. of hard gravel, and 9 ft. of strong clay, giving a total depth of 18 ft., to which the piles were screwed. The average rate of progress in the Eau Brink Viaduct, after a pile had been pitched into proper position, was 8 lineal feet a day. At the Solway Viaduct, where screw piles were abandoned, about twenty experimental corkscrew piles were screwed down to a depth of 8 or 9 ft. by horse power. Four levers of oak, bound round with hoop iron, each lever being 24 ft. long, were fitted into a disc on the pile, and the horses worked at the end of the lever. By this method a pile was got down to a depth of 8 or 9 ft. in a couple of hours. Although the material in this instance was so exceedingly hard as to cause the piles to be driven, the experiment proves that horse power can be effectually employed in screwing piles, where the sands of an estuary or banks of a tidal river are dry at low water.

In screwing down the piles on the bridges of the Midland Railway crossing the Avon, the piles were 2 ft. 6 in in diameter, with a screw of 4 ft. 9 in. in diameter. They were screwed into place from fixed staging by means of an apparatus which consisted of a solid cast-iron hexagonal shaft, bolted on to the head of the pile to be screwed down. This shaft was passed through the centre of a cast-iron wheel having a diameter of 5 ft. A sufficient space was left between the sides of the shaft and the sides of the opening in the centre of the wheel, to allow for the gradual sinking of the pile. Teeth similar to those of a mitre-wheel were placed on the outer rim of this wheel. It was in fact a worm-wheel worked by a worm-screw fixed on a shaft, which was turned by handles very much like a common winch. At some of these bridges beds of thin shaly rock were met with, and were cut through by having a piece of pile 9 in. long cast on below the screw. This piece was cast with saw teeth at the bottom and with sharp ribs up its length, and these acted as cutters. By this plan rock of considerable hardness could be cut through, and if it were sufficiently compact, a hole 9 in. in depth and 18 in in diameter was made, which formed a capital seat for the foot of the pile, and helped to keep it in position, the bottom of the screw resting on the top of the rock.

An ingenious method of using small screw piles for anchoring masses of brushwood for the purpose of regulating the course of rivers was observed in India by Goodwyn. The screw piles were about 7 ft. in length, as shown in Fig. 6373, and made of iron ¾ in. or 1 in. in diameter, the screw being 5½ in. in diameter, formed of sheet iron ⅛ in. in thickness, and with about 2 in. pitch. Each rod was pointed at the lower end and formed roughly into an eye at the top. The piles were screwed into their places with hardly any exertion of strength, by means of handspikes. This plan was tried with great success on the Ganges. It is something similar to the method practised by the Italians, and for the same purpose too. The name they bestow upon it is equivalent to what we should term elastic piling.

6373.



See Docks. Lights, Buoys, and Beacons.

PILLOW. Fr., *Grain*; Ger., *Zapfenlager*, or *Pfaune*; Ital., *Frustagno*; Span., *Almohada*.

In mechanics a piece of metal or wood introduced into machinery with a view to support some part of it to equalize the pressure, is called a pillow. See Pillow-block.

PILLOW-BLOCK. Fr., *Grain d'un tourillon*; Ger., *Lagersitz*; Ital., *Sostegno*; Span., *Tejuelo*.

A pillow-block is a block or standard for supporting the end of a shaft. It is usually bolted to the frame or foundation of a machine, and is furnished with bearings of brass or wood for diminishing the friction of the shaft, and a movable cover or cap for tightening the bearings by means of screws; called also a journal-box, and a plumber-box.

PINION. Fr., *Pignon*, Ger., *Getriebe*, Ital., *Rocchetto*; Span., *Piñon*.

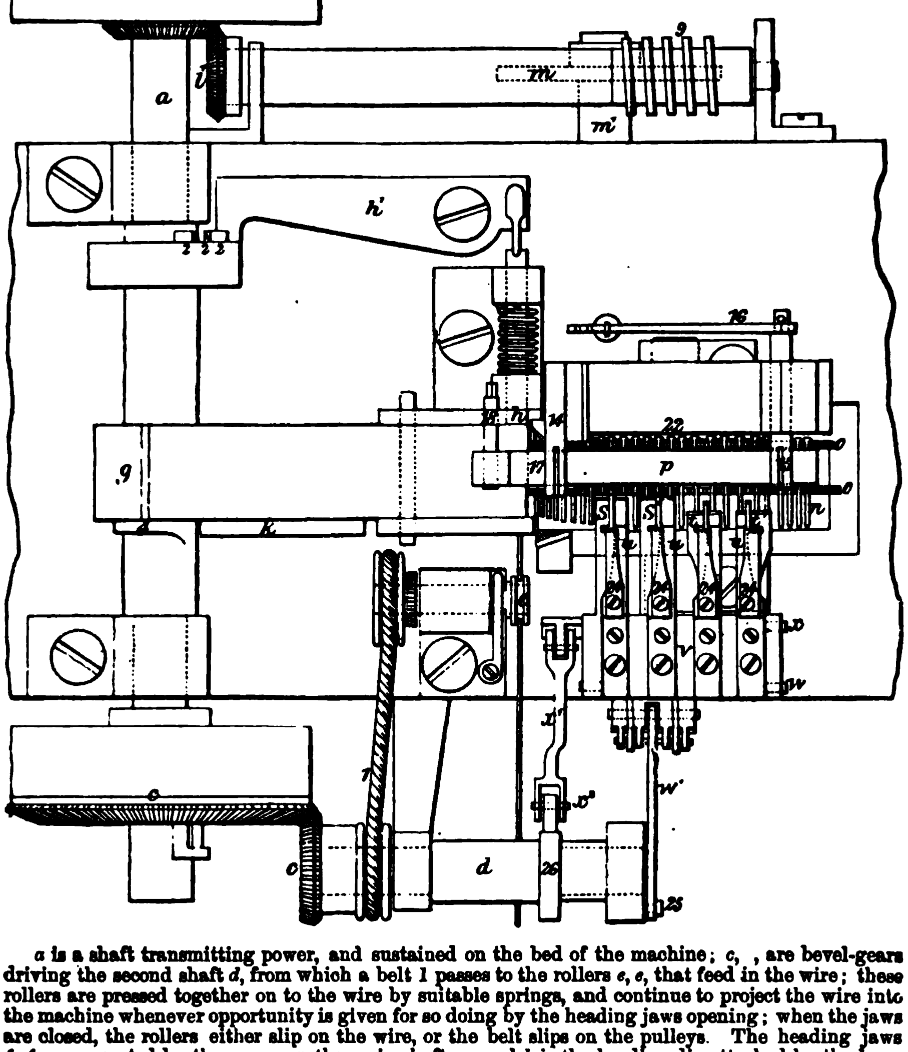
A smaller wheel with leaves or teeth working into the teeth of a larger wheel or a rack;

especially if such a wheel has its leaves formed of the substance of the arbor or spindle on which it turns; is called a pinion.

PIN-MAKING MACHINE. Fr., *Machine à faire les épingles*; Ger., *Maschine zur Fabrikation von Stecknadeln*; Ital., *Macchina da spilli*; Span., *Máquina para hacer alfileres.*

The ingenious machinery designed by T. and De G. Fowler, of Connecticut, U.S., for manufacturing pins, is illustrated by Figs. 6374 to 6381. Fig. 6374 is a plan of Fowlers' machine; Fig. 6375, side elevation; Fig. 6376, vertical longitudinal section; Fig. 6377, cross-section through the rolling bed; Fig. 6378, plan of the heading and cutting die and the rolling bed; Fig. 6379, plan of Fowlers' machine for finishing the pins; Fig. 6380, an elevation.

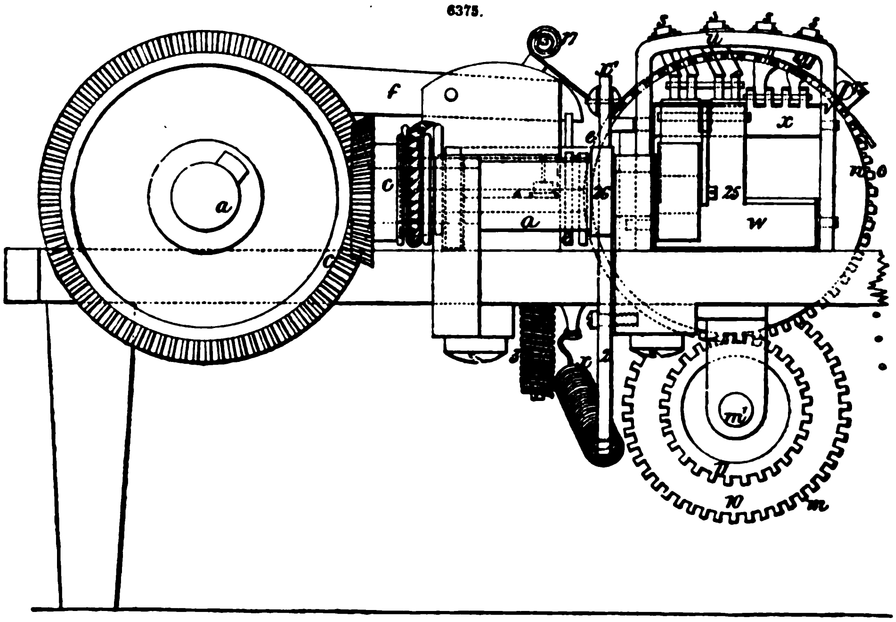
6374.



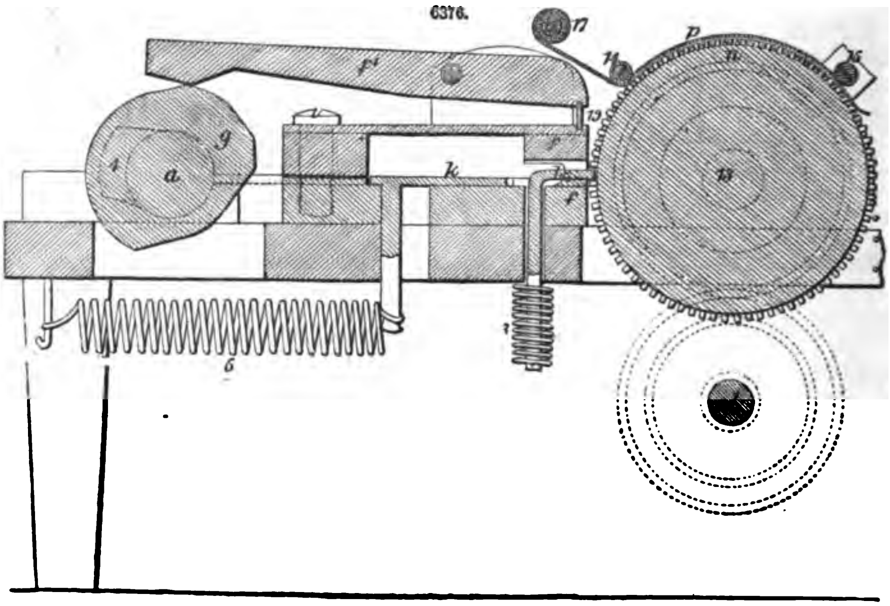
a is a shaft transmitting power, and sustained on the bed of the machine; *c*, , are bevel-gears driving the second shaft *d*, from which a belt 1 passes to the rollers *e*, *e*, that feed in the wire; these rollers are pressed together on to the wire by suitable springs, and continue to project the wire into the machine whenever opportunity is given for so doing by the heading jaws opening; when the jaws are closed, the rollers either slip on the wire, or the belt slips on the pulleys. The heading jaws *f*, *f*, are operated by the cam *g* on the main shaft *a*; and *h* is the heading die attached by the lever h^1 and cams 2, 2, 2. The wire passes into grooves between the jaws *f*, *f*, and is by them clamped at each blow of the header *h*, the jaws releasing the wire slightly between each blow, in consequence of the flat places in the cam *g*, so that the feed-rollers can move the wire slightly endways, as the head is formed by the successive blows. It was once the practice in pin making to open the jaws, cut off the pin, and force it out; this often causes the pin to jump out suddenly, and hence it does not pass properly into the next part of the machine; such action is prevented in Fowlers' machine by the finger *i*, kept down by a slight spring 3, and occupying a cavity formed for that purpose in the upper jaws *f*; the finger has a flaring notch, so that the pin wire can pass along in the groove of the jaw *f* beneath; and when the pin is cut off and passed out of the jaws, this finger presses lightly on the pin, and ensures its proper delivery by the cutter *k*. This cutter *k* is actuated by the cam 4, and drawn back by the spring 5. It has the cutting blade or end 7 acting to separate the wire, and with the projecting toe 8 carry the headed blank out of the jaws *f*, *f*, and deliver it into

the apparatus where the pointing is performed. *l* is a third shaft geared to *a* by mitre-wheels l^1; and 9 is a worm driving the wheel *m* on the cross-shaft m^1. This shaft m^1 has on it gears 10 and 11; the former connects to and drives the wheel and rolling bed *n* on the shaft 13. The rolling bed is composed of rings keyed or secured on to the shaft, and receiving between them the notched pin-wheels *o*, *o*, Fig. 6874; and these notched pin-wheels are driven by the gears 11. The size of the wheels 10, 11, is such that the surface of the rolling bed *n* travels twice as fast as the notches

6375.



6376.



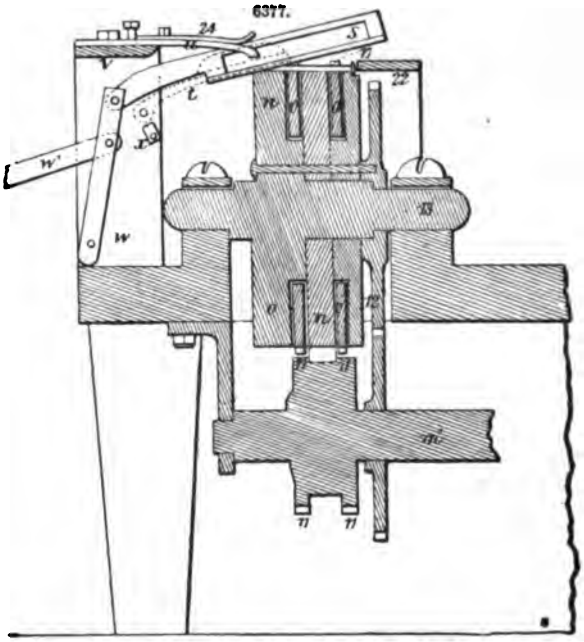
in the wheels *o*, *o*, so that each pin placed in the notches of *o*, by being delivered from the jaws, is rolled round constantly by the joint operation of the rolling bed *n*, notched pin-wheels *o*, *o*, and a resisting stationary surface *p*, formed by a strip of metal between two projecting arms 14, 15, the latter of which is fitted to turn, and provided with a lever 16 and weight or spring to keep the metallic strip towards the rolling bed, with the power and tension necessary to cause the pins to roll. 17 is a thin leather belt between the strip *p* and the pins to make a better bearing surface for the pins to roll against, and this belt is wound on a stud 18, by the turning of which the belt can

be drawn through under the strip *p* to bring a new piece of the belt to the proper place in case of one part wearing out.

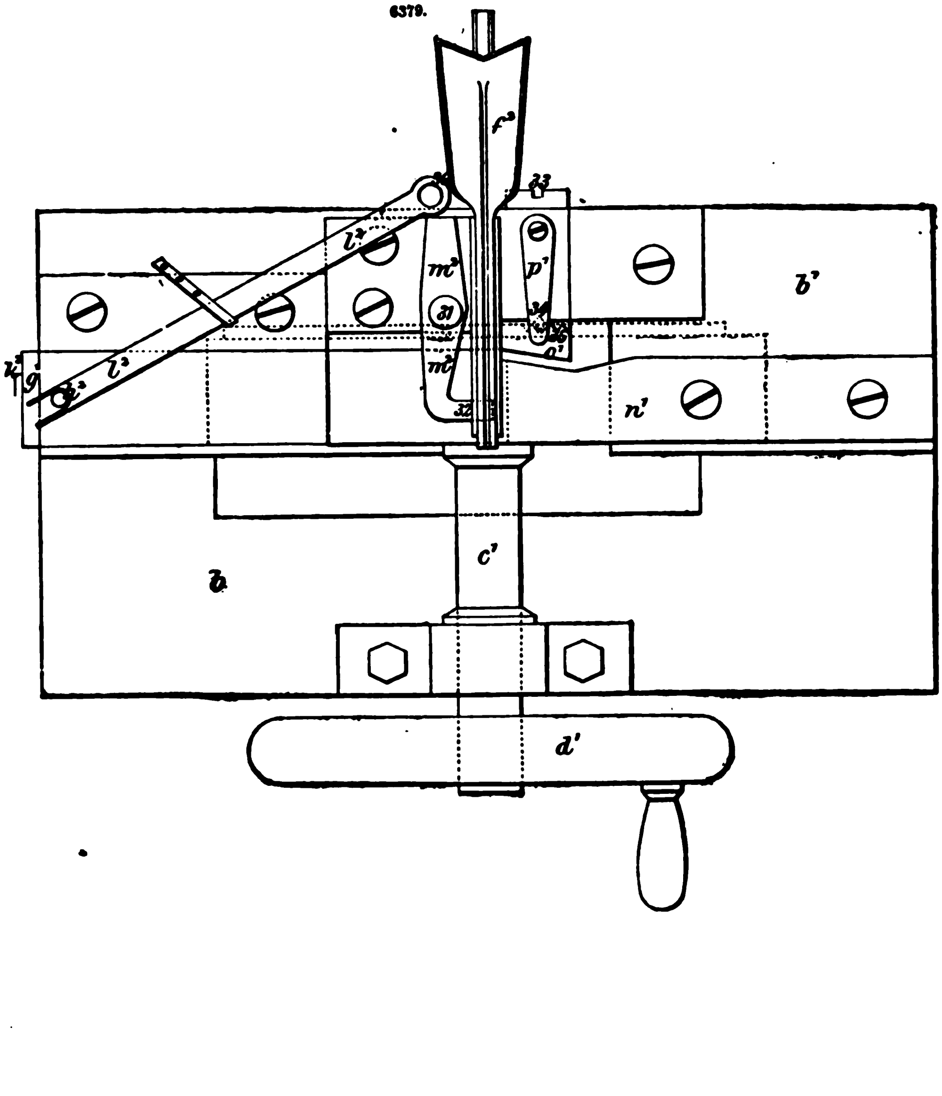
The pins as delivered from the cutting and heading jaws into the notched wheels *o*, *o*, are by them carried up, and a shield 19, Fig. 6378, prevents their falling out, while an incline 20 slides them endways until the heads of the pins take the groove 21 in *n*; and shield 22, behind the heads, prevents the pins being moved endways as pointed. A small grooved compression-plate 23, extended from 22, presses on the pin-heads as they roll beneath it, and, by joint action with the groove 21, compresses and rolls down any slight burr or inequality in the heads. The pins after being pointed fall out into any suitable conductor or receptacle, or are removed from the notched wheels *o*, *o*, by a small stationary tongue of metal, and fall into a trough or receiver.

The device for pointing consists of several files or cutters; we have shown four, two of them

6377.

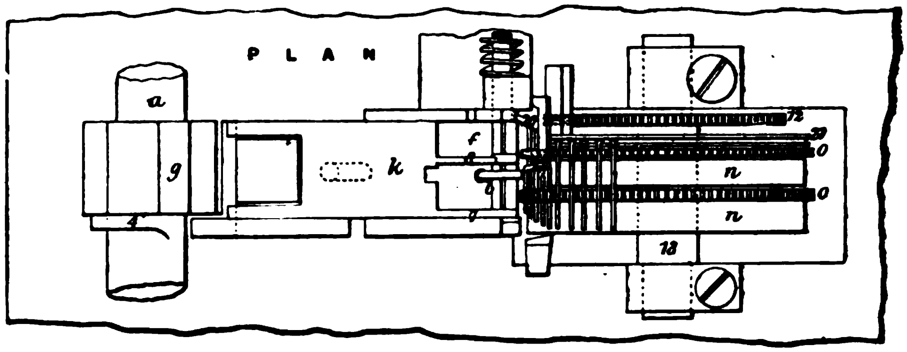


6379.

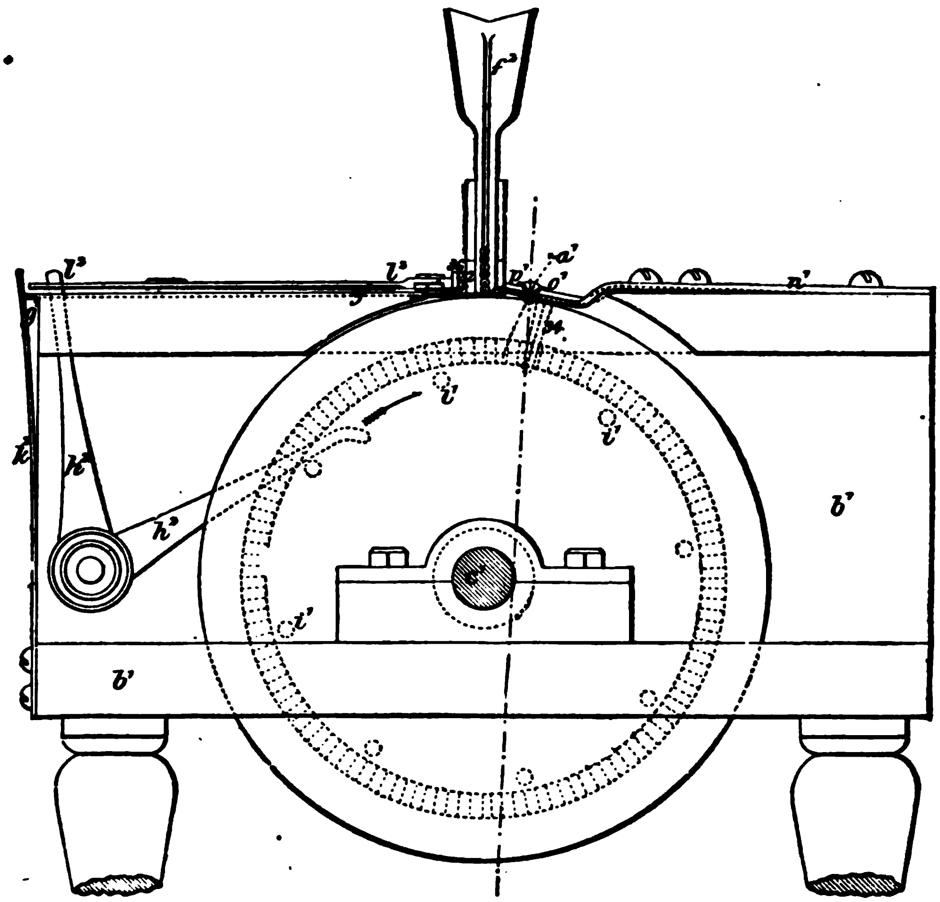


have a long sweep or movement for taking off the metal and shaping the point, the other two have a less movement, and are finer cutters to burnish and finish the points. Each of these cutters *s*, *s*, *t*, *t*, is formed with a slide on the upper part, working through an arm *u*, extending from the arch *v*, and springs 24 pressing the cutters down. The arms *u*, *u*, may be adjustable by set screws, so as to prevent the cutters touching the edge of the rolling bed *n*, or removing too much of the pin point.

6378.



6380.



The cutters *s*, *s*, are reciprocated by the rock-shaft *w* and connecting rod w^1 to the crank-pin 25 on the end of the shaft *d*; and the cutters *t*, *t*, are reciprocated by the rock-shaft *x*, connecting rod x^1, and lever x^2, operated on by cam 26 on the shaft *d*. This cam, having three or more points, gives a short quick movement to the finishing cutters *t*, *t*, while the roughing cutters *s*, *s*, receive a longer and slower movement.

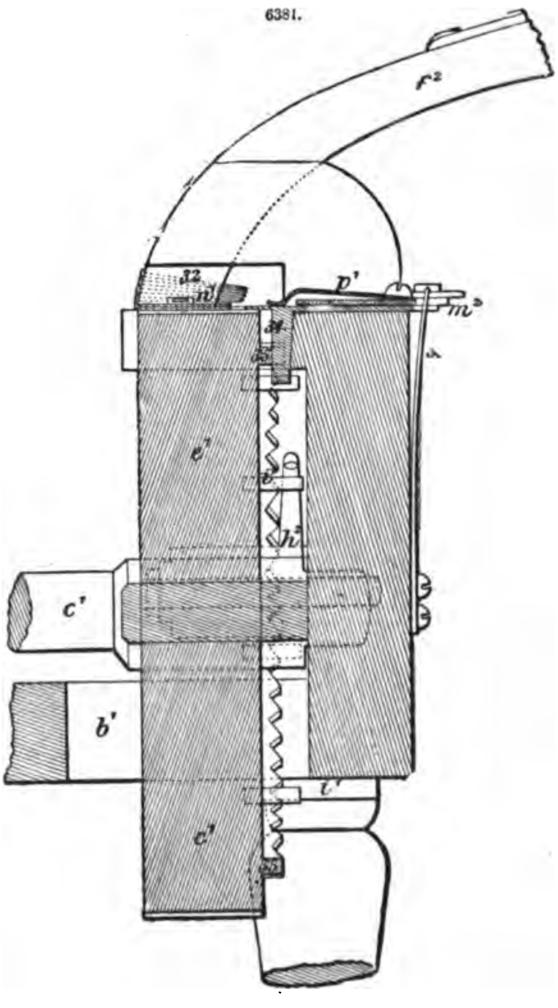
The stationary resisting surface p being curved to the rolling bed, a thin plate only need be used under tension, and thus but little space is occupied above the pin; cutters of any desired length can be used and made to vibrate freely over the points; this is of considerable importance, particularly in pointing iron pins. The movement given to the cutters from the rock-shaft w dresses the points in a convex curved form, the best shape for penetrating easily.

It will be seen that the pins roll under the cutters, and that these cutters, acting on the same side as the stationary resisting surface, do not interfere in the least with the pin rolling freely and revolving as it rolls.

The machinery above described is especially adapted to making pins out of iron wire; we therefore proceed to describe the mode of finishing such iron pins.

Pins were formerly formed of iron by the ordinary cutting, heading, and pointing machinery, and afterwards coated by boiling in tin, similar to brass pins; but the coating put on is so thin that the iron is liable to discolour and rust. When a thicker coating of tin is put on the pin by dipping the pins, or by any ordinary process for depositing such coating metal on the pins, they become very rough in their surface, so that they will not pass into or through any fabric with ease, because such coating exists on the surface in minute granules. If the pins after being thus coated are subjected to any of the known polishing operations, such as the revolving or shaking box, the inequalities of surface are not removed, and considerable power is required to stick the pin in the fabric, as well as giving an unpleasant sensation to the hand. Fowlers' machinery finishes the pins, when coated, by a rolling and compressing operation, in which the granules are crushed down to a perfect bevel, and the pin rendered smooth and uniform throughout its entire length. To accomplish this, they make use of a wheel e^1 mounted on a shaft c^1, that is sustained on a frame b^1, and rotated by the fly-wheel d^1, Figs. 6379, 6380. f^2 is the conductor on to which the pins are placed, whence they pass down the curved end of the conductor, and lie horizontally, as seen in Fig. 6381, which is a vertical section at the line a^1, a^1, Fig. 6379. From the conductor the pins are separated, one at a time, by the slide g^1, that is moved by the lever h^2, acted on by the pins i^1, i^1, at the back of the wheel e^1. k^3 is a spring to keep the lever h^2 towards the pin i^1; l^2 is a slide, acting on the levers m^2, set on the fulcrum 31, and formed with a chisel-shaped separator 32; 36 is a spring acting against the end of the lever m^2. p^1 presses a pin along from beneath the end of the conductor to be acted on, at which moment the separator 32 is drawn back, and the line of pins rests on the slide g^1. Now, as the slide g^1 draws back, the separator 32 passes above the lowest pin, sustaining the others above; while this lowest pin falls on the wheel e^1 as slide g^1 draws from under it. n^1 is a spring compressing plate, coinciding near its end with the shape of the edge of the wheel e^1. 37 is a screw, by which the spring compressing plate is kept towards e^1 with more or less power. The end of this plate n^1 is slightly bevelled, so that each pin is pressed in between the wheel e^1 and plate n^1. The revolution of the wheel e^1 rolls the pin around, and, both surfaces being very smooth, all the inequalities and roughness consequent on the tinning operation are rolled down, and a perfectly smooth and highly-finished pin is produced. The finished pin passes away from beneath the plate n^1 before another is entered, so that any slight inequality in size will not affect the perfect operation and uniformity of pressure on the pin. The point is finished up by the vibrating polisher o^1, kept on to the point by the spring p^1, and vibrated by the joint operation of the spring 33 and a series of teeth 35 around the back of the wheel e^1, acting on a stud 34 from the slide o^1.

6381.



PIPES. Fr., *Tuyaux de conduite, Tubes*; Ger., *Röhren*; Ital., *Tubo*; Span., *Tubos*.

The advance of engineering science has raised the subject of pipes and piping into one of great importance. The improvements recently effected in the manufacture of these articles has vastly extended the field of their application, and it seems probable that the future will develop their use in a still higher degree. The ancients, as far as we are aware, made only a very limited use of pipes; though the Romans, many of whose works yet remain as monuments of their knowledge and skill in hydraulic engineering, carried their systems of town water-supply to a high degree of perfection, they everywhere preferred brick or stone conduits to the lead piping which alone they had at their disposal. Only in cases where no alternative remained did they resort to this latter mode of conveying more than very small quantities of water, and the extreme timidity with which they employed it in such cases, as shown by still existing works, testifies whence their reluctance proceeded. Nor was this timidity ill-founded. The material, as we have said, was lead, and the pipes were made of long strips by bending them upon a cylindrical object and joining the edges. Thus they were ill-adapted for the conveyance of water under pressure. The improvements of recent years, however, by which lead pipes are readily formed without a joint, have removed the latter source of insecurity, and rendered them applicable wherever the character of the material may be considered suitable. A far greater advance was the adoption of iron as the material of construction. The nature of iron being such that pipes may be made of it of any form and dimensions, and capable of withstanding any pressure, the difficulties that attended their employment in former times no longer exist. Hence the general substitution of a system of pipes for that of stone or brick conduits, as well as their application to numerous other important uses.

Another material, that of stoneware, has also assumed a rank of the highest importance for pipes designed for drainage purposes, and the degree of perfection to which their manufacture is now carried promises to develop their use still further.

Iron Pipes.—Both cast and wrought iron is extensively used in the manufacture of pipes; the former kind is, however, the more frequently employed, as water and gas pipes are made almost exclusively of that material. In some respects the nature of cast iron is more suitable for pipes to be used for those purposes than that of wrought iron. The tensile strength of the material is, in such cases, of less importance than its ability to withstand compression, for the weight of the earth pressing upon a water-main laid several feet beneath the surface is usually greater than the internal pressure of the water, while in the case of gas-pipes the strain is practically one of compression only. But a more important quality is its susceptibility of being moulded into any required shape,—a quality that renders it well adapted for the formation of pipes, varied forms of which are continually required.

The manufacture of cast-iron pipes is, however, attended with more difficulty than usually attaches to castings of a different character. The thickness of the metal being often no more than half an inch, any imperfection causes a serious diminution of strength, and this slight thickness increases the liability to imperfection. Cast iron is classed according to the amount of carbon in combination with the iron, and the proper admixture of the various kinds in the foundry is a matter of the highest importance. The different kinds of iron have different points of fusion and different rates of cooling; therefore, if a due admixture be not made, one portion will be fused before another, and consequently will be burnt before the remainder has been raised to its proper degree of heat; or one part becomes solidified while the other remains in a state of fusion, and hence the casting will contain within itself the elements of its own destruction, by being brought into a state of unequal tension, or, as it is technically termed, hide-bound. A hide-bound pipe is liable to be destroyed by a sudden and sometimes slight change of temperature, a cold rain being especially likely to cause fracture. Baldwin Latham mentions a case that came under his notice at Croydon, where a 12-in. main, ½ in. thick, which, previously to its being laid, had been subjected to a pressure of 500 ft. head of water, burst in several parts with a pressure of only 150 ft. head, after a heavy rain followed by snow. Inquiries proved that these pipes had been hastily made, and had become hide-bound by being too rapidly cooled. Metal which has been reheated in the air-furnace has been found to possess a somewhat greater tensile strength than metal which has not been so reheated, and it is the practice of some manufacturers to repeat their castings for pipes in the same way. But more frequently they are cast direct from the blast furnace. No harm can result from this latter method if due care is taken. The experienced workman knows by the bloom upon the molten mass whether or not it is fit for a pipe-casting, and if unfit he pours it into pigs to be remelted with an admixture of other kinds in the air-furnace.

The presence of phosphorus in the iron renders it brittle and very liable to fracture; this quality is technically known as cold-short. Cold-short iron should never be used for pipes. The presence of arsenic, on the contrary, is said to improve the quality of the iron. It is, perhaps, scarcely necessary to state that castings for pipes must be kept free of scoria and air-bubbles. The presence of the latter may often be detected by sounding the pipe in every part with a hammer. Whenever an air-bubble is detected, or even if its presence is suspected, the pipe should be thrown aside as dangerous, if it is to be subjected to considerable pressure. To prevent air-bubbles remaining in the metal, pipes are often cast with a head, that is, with a mass of metal above that requisite for the pipe itself. This head compresses the mass below, and receives the air-bubbles which ascend into it. When the casting has cooled, the head is cut off. Pipes produced in this manner are stronger and much more trustworthy than those cast without a head.

Small pipes are usually cast horizontally, or inclined at an angle of 45°. When large pipes are cast in this position the cores have a tendency to float, and so to give a greater thickness on one side than the other. Moreover, pipes which have been cast horizontally are not so strong as those which have been cast vertically. The latter position should therefore be adopted for all but small pipes. The same defect of having a greater thickness on one side than the other may occur in pipes cast vertically if care is not taken to place the core truly concentric, or if it warps during the process of drying. In vertical castings the socket end of the pipe is usually placed downwards,

but this position may be reversed if required. It is important that all pipe-castings should be truly cylindrical, as otherwise the spigot ends will not fit the sockets. The thickness of a cast-iron pipe is determined as much by the nature of the material as by the strain to which it is to be subjected. Cast iron is slightly porous, and is liable to many and considerable defects in casting, especially when the metal is thin, as in the case of pipes. Therefore a sufficient thickness is always given by the founder to ensure a perfect casting. This thickness, except for very small pipes, is never less than ½ in., and as a pipe ½ in. thick is sufficiently strong to bear with safety any ordinary pressure, it may be stated that, for ordinary cases, any pipe is, with respect to its thickness, sufficient for the purpose required. When, however, the pressure is to be excessive, or when the pipe is to be subjected to shocks, the proper thickness must be found by calculation.

All pipes before being used should be tested by hydraulic pressure up to three or four times the head they will have to bear. They should also be carefully rung all over the surface with a hammer to detect the presence of air-bubbles. As to appearance, they should show on the outer surface a smooth, clear, and continuous skin. When broken, the surface of fracture should be of a light bluish-grey colour and close-grained texture, and both colour and texture should be uniform. It may be remarked, however, that the colour will be somewhat lighter, and the grain closer, near the skin, in consequence of the chilling which takes place there in casting. The iron should be soft enough to be slightly indented by a blow of a hammer on the edge.

In calculating the requisite thickness of a cast-iron pipe under given conditions, it must be borne in mind that, whatever care is taken, it is impossible to keep the core always perfectly central, and that, therefore, a pipe will have an excess of metal on one side, and a corresponding defect on the other. And as the strength of a pipe depends upon its weakest part, due allowance must be made for this defect. When all the imperfections to which a cast-iron pipe is liable are taken into consideration, it will be seen that, to obtain perfect security from accident, the factor of safety must be taken large. Many engineers take it at six, others at ten, the latter we think the most prudent course. The passage of heavy traffic along the roads, and the turning off of cocks, frequently bring a sudden strain upon a pipe, which the nature of its material is ill-adapted to bear. It is a common practice for engineers to calculate the weight of a pipe of the requisite thickness, and to specify the weight rather than the thickness, leaving the founder to fix that for himself, which long practice enables him to do with considerable precision. Absolute correctness, of course, cannot be obtained, and a margin of 1 lb. to an inch either way is usually allowed.

The resistance which a pipe offers to the internal pressure tending to burst it is equal to the cohesive strength of its two sides, and the effective area of that pressure is the internal diameter of the pipe. If the tensile strength of cast iron is taken as 15,000 lbs. to the square inch, the thickness of a pipe to be subjected to water-pressure will be given by the formula

$$\frac{\cdot 433\ \mathrm{H\ R}}{15000} = \cdot 0000288\ \mathrm{H\ R},$$

in which H represents the head of water in feet, and R the radius of the pipe in inches. Substituting the diameter for the radius, the formula becomes $\cdot 0000144$ H D. A pipe having this thickness is strained up to the bursting point. If we take ten as the factor of safety in accordance with the opinion expressed above, we have as the formula giving the requisite thickness in practice, $t = \cdot 000144$ H D. Thus, suppose a 10-in. pipe to be subjected to a pressure of 200 ft. head. The requisite thickness, as given by the formula, is $\cdot 000144 \times 200 \times 10 = \cdot 288$ in. This is less than the necessary practical thickness to which we have alluded above, and therefore the least thickness that can be cast will possess an excess of strength in this case. If the head were 400 ft. the thickness would be $\cdot 000144 \times 400 \times 10 = \cdot 576$ in. In this case, the specified thickness would be ⅝ in. Pipes are usually tested by hydraulic pressure up to twice their working pressure, and engineers frequently calculate the thickness from this head. But if the factor of safety is taken equal to ten, such a proceeding can hardly be considered justifiable.

Molesworth gives the following formula for finding the thickness of cast-iron pipes;— $t = \cdot 000054$ H D $+ x$, in which H and D have the same signification as above, and x is a constant quantity equalling $\cdot 37$ in. for pipes less than 12 in. in diameter; $\cdot 50$ in. for pipes from 12 to 30 in., and $\cdot 60$ in. for pipes from 30 to 50 in. in diameter. The example given above, calculated by this formula, becomes $\cdot 000054 \times 400 \times 10 + \cdot 37 = \cdot 586$ in., a result nearly identical with that given by the first formula. The formula generally used by French engineers is $t = \cdot 0016nd + \cdot 008$, in which t = the thickness in fractions of a mètre, n = the effective pressure in atmospheres to the square mètre, and d = the diameter of the pipe. The constant quantity, $\cdot 008$ mètre, is the excess of thickness given to render the pipe capable of bearing a sudden shock. The water-pipes of Paris, as well as those of several other large towns of France, were calculated from this formula.

The weight of a cast-iron pipe may be found by multiplying the cubical contents in inches by $\cdot 26$ lb., the weight of a cubic inch of cast iron; or the weight of a yard may be determined by the following formula; $\mathrm{W} = 7 \cdot 35\,(\mathrm{D}^2 - d^2)$, in which D represents the outside, and d the inside diameter in inches. The weight of two flanges is equal to about 1 ft. of pipe; the faucet adds from $\frac{1}{10}$ to $\frac{1}{15}$ of the weight of the pipe. The usual length of a cast-iron pipe, exclusive of the faucet, is 9 ft. Suppose now 10-in. pipes are required, capable of bearing safely a pressure of 400 ft. of water. We have shown that in this case the requisite thickness is ⅝ in. The outer diameter will therefore be 11¼ in. Hence, the weight of the whole pipe will be

$$3 \times 7 \cdot 35\,(126 \cdot 56 - 100) + \frac{22 \cdot 05 \times 26 \cdot 56}{15} = 624 \text{ lbs.},$$

taking the weight of the faucet as $\frac{1}{15}$ that of the pipe. The weight specified to the founder will thus be 5 cwt. 2 qrs. 8 lbs. And allowing a margin of 1 lb. to the inch of diameter, the pipe delivered may weigh anything between 5 cwt. 1 qr. 26 lbs., and 5 cwt. 2 qrs. 18 lbs.

We come now to consider certain matters connected with the use of iron pipes; and first in importance among these is the resistance which their walls offer to the passage of water. In every system of town water-supply or drainage, the friction of the water in the long succession of pipes through which it is conveyed, causes a considerable diminution in the quantity discharged under a given head of pressure, and the extent of this diminution, or as it is usually termed, the loss of head, must be ascertained before the diameter of the pipe requisite to convey a certain volume of water can be determined. It has been found by experiment that this friction depends on the velocity of the water and the diameter of the pipe, and that it increases very rapidly with the velocity. The very elaborate experiments devised and carried out by M. Darcy have led to the establishment of formulæ which give the value of the friction with sufficient accuracy for practical purposes. Let A be the sectional area of a pipe, b its border or inner circumference, and l its length. Then $l\,b$ is the frictional surface, and $\frac{A}{b}$ is the hydraulic mean depth, which, for cylindrical pipes running full, is obviously one-fourth of the diameter. Then $F = \frac{f\,l,}{\frac{1}{4}\,D}$, F being the friction between the water and the sides of the pipe, D its diameter, and f a coefficient, the value of which, as given by Darcy, is $\cdot 005\left(1 + \frac{1}{48\,m\ (\text{feet})}\right)$, m being substituted for $\frac{1}{4}$ D. Usually, however, formulæ for the discharge of pipes or the requisite head of water are employed in which this friction is taken into account. The following are of this kind;—

$$G = \sqrt{\frac{(3\,d)^5 \times H}{L}}. \qquad H = \frac{G^2 \times L}{(3\,d)^5}, \qquad L = \frac{(3\,d)^5 \times H}{G^2}, \qquad d = \sqrt[5]{\frac{G^2 \times L}{H}} + 3.$$

In which G = the discharge in gallons a minute, H = head of water in feet, L = length of pipe in yards, and d = diameter of pipe in inches. Thus, let it be required to find the discharge of a 6-in. pipe 2500 yds. long under a head of 50 ft. From the first formula we have

$$G = \sqrt{\frac{(18)^5 \times 50}{2500}} = \frac{5 \times \log. 18 + \log. 50 - \log\ 2500}{2} = \log. 194\cdot 4 \text{ gallons.}$$

Again, let it be required to find the diameter of a pipe 2500 yds. long, which, with a head of 50 ft., shall be capable of discharging 194·4 gallons a minute. From the fourth formula we have

$$d = \sqrt[5]{\frac{(194\cdot 4)^2 \times 2500}{50}} + 3 = \frac{2 \times \log. 194\cdot 4 + \log. 2500 - \log. 50}{5} - \log. 3 = \log. 6 \text{ in.}$$

In a similar manner H and L may be found from the second and third formulæ. These formulæ are given by Thos. Box in his Practical Hydraulics, and the Tables given in that valuable little book were calculated from them. They give very accurate results, and are very convenient in practice. Other formulæ are, however, in common use. The following, for instance, known as Eytelwein's, is very generally employed;—

$$W = 4\cdot 72\sqrt{\frac{D}{L}} \qquad D = 538\sqrt[5]{\frac{L\,W^2}{H}},$$

in which W is the discharge in cubic feet a minute, and L the length of pipe in feet, D and H having the same value as in the preceding. The foregoing example calculated by this formula becomes $\frac{5 \times \log. 6 + \log. 50 - \log. 7500}{2} + \log. 4\cdot 72 = \log. 33\cdot 98$ cub. ft. = 212 gallons a minute, or about 9 per cent. more than in the first case. Another formula known as Hawksley's is

$$G = \sqrt{\frac{(15\ D)^5\ H}{L}}, \text{ whence } D = \tfrac{1}{15}\sqrt[5]{\frac{G^2\,L}{H}},$$

G being the discharge in gallons an hour, and H, L, and D have the same signification as in the first case. With this formula the example becomes $\frac{5 \times \log. 90 + \log. 50 - \log. 2500}{2} = \log. 10869 = 181$ gallons a minute, or about 7 per cent. less than in the first case. Neville's general formula, from which many practical tables have been calculated, is as follows; $v = 140\sqrt{r\,s} - 11\sqrt[3]{r\,s}$, v being the velocity in feet a second, r the hydraulic mean depth in feet, and s the sign of the inclination, or the total fall divided by the total length. In cylindrical pipes the discharge in gallons a minute $= 293\cdot 7286\ d^2\ v$, d being the diameter of the pipe in feet. Taking again the same example, we have

$$\log. 140 + \frac{\log. \cdot 125 + \log. \cdot 0066}{2} - \left(\log. 11 + \frac{\log. \cdot 125 + \log. \cdot 0066}{3}\right) + \log. \cdot 25 + \log. 293\cdot 7286$$

$= \log. 219\cdot 3$ gallons a minute, or about 13 per cent. greater than in the first case. When the great length of pipe is taken into consideration, the difference in the results obtained by these several formulæ will be seen to be of little practical importance.

It must be remarked that the preceding formulæ apply only to clean pipes. Darcy's experiments showed that the effect of corrosion was to double the friction; consequently it will be necessary in the case of corroded pipes to double the head due to friction as found by the formulæ. A case is recorded as having occurred at Torquay, where a main about 14 miles long, composed of 14,267 yds.

of 10-in., 10,085 yds. of 9-in., and 170 yds. of 8-in. pipe, delivered only 317 gallons a minute with 465 ft. head. An ingenious scraper, worked by the pressure of the water, was passed several times through the pipes, the result being a discharge of 634 gallons. The best preservative for cast-iron pipes against corrosion is a coating of pitch, applied both inside and out, by a process which makes it penetrate the pores of the iron and adhere very firmly. Angus Smith's process of black enamelling has proved very efficacious. It can only be applied while the pipes are new and hot, and must consequently be done by the founder.

Besides the loss of head from friction, there is frequently another loss due to change of direction, caused by bends and angles in the pipes. When the bends are of large radius and are not numerous, their influence may be neglected, but angles and bends of a small radius occasion a considerable loss. The most convenient formulæ applicable to such cases are the following;—For knees, $H = \cdot 0155\,V^2 K$, and for bends $H = \cdot 0155\,V^2 \left(\frac{A}{180} L\right)$, in which H is the head of water in feet, V the velocity of the water in feet a second, A the angle of bend or knee with forward line of direction, and K and L are coefficients for angles of knees and curvature of bends respectively. The values of K for angles of 20°, 40°, 60°, 80°, 90°, 100°, and 120°, are respectively ·046, ·139, ·364, ·74, ·93, 1·26, and 1·86. The values of L when the ratios of the radius of the centre line of bend to radius of bore are ·1, ·2, ·3, ·4, ·5, ·6, ·7, ·8, ·9, 1·0, are respectively ·131, ·138, ·158, ·206, ·294, ·44, ·66, ·98, 1·4, and 2·0. Weisbach's formula for the resistance of bends is, $R = \frac{\theta}{\pi}\left\{0\cdot 131 + 1\cdot 847\left(\frac{d}{2r}\right)^{\frac{7}{2}}\right\}$, and for knees $R = 0\cdot 946\,\sin.^2\frac{\theta}{2} + 2\cdot 05\,\sin.^4\frac{\theta}{2}$, in which d is the diameter of the pipe, r the radius of curvature of its centre line at the bend, θ the angle through which it is bent, and π two right angles. The first of these formulæ may be modified into the following; $H = \left\{0\cdot 131 + 1\cdot 847 \times \left(\frac{r}{R}\right)^{\frac{7}{2}}\right\} \times \frac{V^2 \times \theta}{960}$, in which H represents the head in inches, due to the change of direction, r the radius of the bore of the pipe in inches, R the radius of curvature of the centre line of the bend in inches, and V the velocity of discharge in feet a second.

To the head due to friction and to the resistance offered by bends, there yet remains to add the head due to the velocity of entry. In long mains this quantity is so small a proportion of that due to friction that it may be neglected without sensible error; but in short pipes it may be much greater than the head due to friction, and therefore in such cases it cannot, of course, be neglected. This head may be found by the formula $H = \left(\frac{G}{d^2 \times 13}\right)^2$, in which H is the head in feet, d the diameter of the pipe, and G the discharge in gallons a minute. Thus it will be seen that the total head consists of three parts, that due to friction, that occasioned by the changes of direction, and that due to the velocity at entry.

A long main is usually composed of pipes of different sizes, and in computing the discharge of such mains, the head for each must be separately calculated, and the total sum taken. Suppose, for example, we have a main consisting of 500 yds. of 8-in., 200 yds. of 7-in., and 100 yds. of 6-in. pipes, through which it is required to discharge 200 gallons a minute. For the friction of the 8-in. pipe we require a head of 2·50 ft., for that of the 7-in. a head of 1·96 ft., and for that of the 6-in. a head of 2·10 ft. The total head requisite for the whole main is $2\cdot 50 + 1\cdot 96 + 2\cdot 10 = 6\cdot 56$ ft. To this must be added the head due to the velocity of entry, and, if there are bends, that due to changes of direction.

When it is required to determine the discharge through such a series of pipes with a given head, the case does not admit of a direct solution, because we do not know beforehand in what proportions the given head is to be divided among the different pipes. We must therefore, in such cases, apply the general law that *the discharge of any pipe, or series of pipes, is proportional to the square root of the head*, and, conversely, *the head is proportional to the square of the discharge*. For example, suppose in the above case we have a head of 10 ft., and it is required to determine the discharge. Assume a discharge of, say, 200 gallons a minute. It matters not whether the assumed discharge is near the truth or not. The sum of the heads required is, as we have seen, 6·56 ft., and we will suppose the head due to velocity of entry and changes of direction to be ·19 ft. The total head will thus be 6·75 ft. Then by applying the above general law we have $\frac{\sqrt{10} \times 200}{\sqrt{6\cdot 75}} = 243$ gallons, the actual discharge.

The sizes of street service-pipes for a town water-supply are not calculated by the methods applied to the mains. It has been found by experience that a certain size lead pipe is necessary for a house containing a given number of rooms. For an intermittent supply, the usual sizes are $\frac{1}{2}$-in. pipe for a house with 7 rooms, $\frac{5}{8}$-in. for 10 rooms, $\frac{3}{4}$-in. for 16 rooms, and 1-in. for 25 rooms. The number of service-pipes which a main of a given diameter is capable of supplying is known from the general law, that when the head and length are constant, the discharge is directly as the 2·5 power of the diameter. Thus $4^{2\cdot 5} = 32$, and therefore we may admit that a 4-in. main is capable of supplying 32 1-in. service-pipes. All distributing pipes must be adapted to the greatest hourly demand, and to the requisite head in the streets. The total length required is about a mile to every 2000 inhabitants. Service-pipes should, whenever practicable, be connected at both ends with mains so as to have as few dead ends as possible. When the diameters of the principal mains have been computed by the proper formula, those of the branch mains may be easily deduced from them by the rule that, with equal virtual declivities, the diameters of pipes are to be proportional to the squares of the fifth roots of the quantities of water they are to convey.

If a number of open-topped pipes were inserted at various points along a main, the level of the water in these pipes would mark the line of virtual declivity, or, as it is frequently termed, the hydraulic mean gradient. This line of virtual declivity commences at a point in the reservoir

vertically above the mouth-piece of the pipe, at a depth below the top water equal to the loss of head due to the velocity of flow in the pipes and the friction of the mouth-piece. The mode of determining it is to calculate the loss of head for a series of points in the course of a pipe, and having determined it, care must be taken in laying out the levels that no portion of the pipe be above this line. The reason for this is, that at all points in the pipe situate above the line of virtual declivity the pressure is less than that of the atmosphere; in other words, a partial vacuum is formed. And as water contains a certain quantity of air, the latter would disengage itself from the water and accumulate at these points. A pipe in such conditions is called a siphon, and unless means are provided for getting rid of the accumulations of air, it is incapable of conveying water.

The joints in pipes are usually made either by means of flanges or by spigot and socket. The former of these methods is always used for pumps, and usually whenever water-pipes have to be set vertically. It is also well adapted for joints that are required to be frequently loosened. India-rubber rings form the most convenient kind of joint for flange-pipes. Spigot and socket joints are generally used for water and gas pipes, for besides being more economical than the flange, they possess the advantage of allowing a departure from the strictly straight line by slightly enlarging the diameter of the socket. When the plain end is made to fit the faucet or socket exactly, the joint is made water-tight by means of red-lead paint; in such cases, no deviation from the straight line is admissible. When the spigot and socket are made to fit loosely, the joint is run with lead; and if the socket is made sufficiently large, considerable deviation may be obtained. It must, however, be borne in mind that a good joint cannot be made if the socket is much larger than the spigot. The following Table of the proportions of joints for cast-iron pipes, taken from Box's Practical Hydraulics, shows the most approved practice in these points;—

Diameter of Pipe in inches.	Depth of Socket.	Lead Joints.			Laying a Yard, Prime Cost.	
		Thickness.	Depth.	Weight in lbs.		
	inches	inches.	inches.		s. d.	
1½	3	¼	1½	1·2	0 11	This cost, which includes excavating the ground and making good the same, will of course vary with the nature of the ground and the price of labour, and is only given for the sake of comparison.
2	3	¼	1½	1·4	1 0	
2½	3½	¼	1½	1·6	1 1	
3	3½	¼	1¾	2·3	1 2	
4	4	5/16	2	4·0	1 3	
5	4	5/16	2	5·0	1 5	
6	4½	5/16	2¼	6·5	1 7	
7	4½	5/16	2¼	7·7	1 10	
8	4½	5/16	2¼	8·2	2 1	
9	4½	5/16	2½	10·4	2 6	
10	4½	5/16	2½	11·5	3 4	
12	4½	⅜	2¾	18·0	4 6	

When a joint in a pipe has been made, it is liable to fracture from the settling of the ground. To prevent this, care should be taken to form a good foundation, and to make the pipe bear from end to end. When the ground sinks beneath a joint, that and the next two, one on each side, must necessarily be broken, and the slightest subsidence is sufficient to cause this rupture, since the whole weight of the pipes, with that of the superincumbent earth, is brought to bear upon the joints. If the ground settles down between two joints only, the subsidence of the earth above the pipe tends to rotate the latter, and so to rupture the joint. The same effect is of course produced if the pipe bears only at the ends. A joint may also be broken by the careless filling-in and ramming of the earth, or by the weight of the workmen before a sufficient depth of earth has been laid upon the pipe to destroy the shock of walking. Attention is usually paid to these matters in the case of stoneware pipes and clay joints; but when the pipes are iron and the joints lead, they appear to be supposed capable of withstanding any possible strain or shock. The fact is, however, that a lead joint is very easily ruptured. It is extremely probable from the manner in which water-pipes are laid that a vast number of the joints leak, thus causing a great loss of water in the case of a town supply. Water will not show itself on the surface of the ground unless the upward is the easiest direction, and in two cases out of three it will not be so. The loss, therefore, goes on unperceived. In support of these assertions, we may quote certain facts laid before the American Society of Civil Engineers at New York, on the 19th of March, 1873. Joseph Whitney, of Cambridge, Mass., in a paper on Leakages in Pipes, referred to the great and growing increase in the consumption of water. Rarely is a report of water-works issued which does not refer to this increase as something remarkable, and, at the same time, unaccountable. Whitney's attention was called to this subject at Cambridge, where, for three years preceding, the water-pressure had been growing less, causing much inconvenience and insecurity in case of fire. This was ascribed to the great number of users from one main, an 8-in. pipe. In a particular house the water scarcely rose to the second story, either during the day or at night. After inquiry, a series of observations were made with siphon-pipe and pressure-gauge, for the purpose of determining the cause. These observations were made in the morning when the consumption was nearly nothing; and in one case, by shutting off certain sections from the main—say, a 4-in. or a 6-in. pipe—a large leak was revealed where the pipe, laid in a street filled with oyster-shells, had parted. In another case, when the gate was closed, the water in the siphon at once rose 16 ft., equal to about two stories of an ordinary house. The pipe, about 600 ft. long, and laid upon marshy ground, was examined, and the leak found in a joint, where the two parts had been entirely separated by a settlement of one section. These and other leaks which were detected by

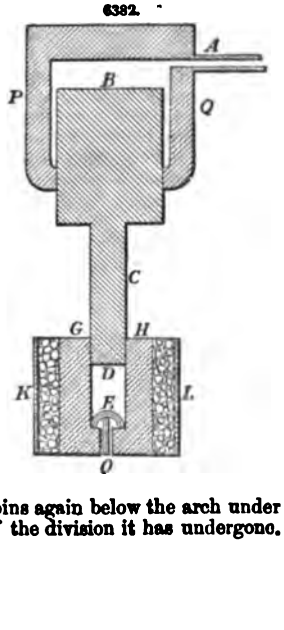
similar means were closed, and thus, without any increase of size in the mains, an additional head of 35 ft. was secured, amply sufficient to give a full supply to every house in the locality. Observations were then made upon the reservoir during the night, and as there was evidence of still existing leakage, further experiments were undertaken upon the pipes throughout the city. The result of these experiments was the discovery of no fewer than *two hundred leaks of from one to two thousand gallons an hour each.* The necessary repairs were made, and thereby the average daily consumption was reduced from 85 to 35 gallons a head. It is probable that this state of things exists in other cities than Cambridge, and it may furnish a sufficient reason for the great increase in the consumption of water which more or less embarrasses public authorities.

In gas-pipes, the pressure being of no importance, the thickness of metal is determined by the exigencies of founding alone. The diameter, however, as in the case of water-pipes, is determined by the volume of fluid to be passed in a given time. The following formulæ give the volume and the diameter; $Q = 1000 \sqrt{\frac{D^5 H}{G L}}$, and $D = \cdot 063 \sqrt[5]{\frac{Q^2 G L}{H}}$, in which Q represents the quantity of gas in cubic feet an hour, L the length of the pipe, D the diameter of the pipe in inches, H the head of water-pressure in inches, and G the specific gravity of gas. For ordinary calculations, G may be assumed = ·45, and H = ½ in. to 1 in. A public lamp consumes 5 cub. ft. of gas an hour; and it has been found by experience that two lamps 40 ft. from main require ⅜-in. bore of pipe, and four lamps at the same distance require ½-in. bore. At a distance of 50 ft. six lamps require a pipe of ⅝-in. bore, and at 100 ft. distant, ten lamps must be supplied with a ¾-in. pipe. The preceding remarks relative to the laying of water-pipes apply equally to gas-pipes.

Pipes that are to be subjected to great internal pressure should be of wrought iron, especially where weight of metal is an important consideration. The tenacity of wrought iron being three times that of cast, the formula $\frac{433\,H\,R}{15000}$ will become $\frac{\cdot 433\,H\,R}{45000} = \cdot 0000096\,H\,R$, and as the factor of safety may be taken at six instead of ten, as in the case of cast iron, we have ·0000576 H R, or ·0000288 H D. Moreover, there are no limits to the thickness of wrought-iron pipes imposed by the processes of manufacture, so that the requisite thickness may be always obtained. To make the above formula general, let P represent the pressure in pounds to the square inch, and F the tenacity of the metal; then the safe thickness $T = \frac{6\,P\,R}{F}$. Wrought iron is also used for pipes of very small bores, as, for instance, small service-pipes for water and gas. When used for these purposes, wrought-iron pipes are much cheaper than lead, and, from a hygienic point of view, vastly superior to the latter for water-supply. They are, however, not so easily fixed as lead, because, to be bent to any requisite angle, they must be heated in a forge, while lead can be beaten cold. This is probably the reason why lead continues to be almost exclusively employed inside a house, in spite of its unwholesome properties, though iron is almost exclusively used outside. The manufacture of wrought-iron pipes is quite of recent origin, but it is now a very extensive branch of industry, especially at Birmingham. They are made by passing plates of iron at welding heat through rollers specially constructed for the purpose. In this way, pipes are produced perfectly true, with a sound longitudinal joint, and of almost any required strength. It is no uncommon thing to test pipes thus manufactured for steam purposes up to 3000 lbs. pressure to the square inch. Pipes of large diameter, made of sheet iron and coated with pitch, have been used in France as mains for a town water-supply.

Lead Pipes.—We have stated above that lead pipe is almost exclusively employed inside of houses. The quantity used in this way is very great, and hence this branch of manufacture is one of very great importance. The perfection to which the manufacture of lead piping has been carried of late years by the aid of hydraulic machinery is one of the most striking features of the industry of the present day. The ancients, as we have seen, formed their pipes of strips of lead by joining the edges. With the machinery in use, lead pipes are produced without a joint by forcing them out of solid lead. Fig. 6382 represents an hydraulic press as applied to this purpose. The press P Q consists of a massive iron cylinder and a piston B C. This piston or plunger is narrowed at the end and turned, so as to fit tightly into a very strong iron cylinder G H. In the bottom of this cylinder is a hole O, which is carefully turned to the exact external size of the pipe to be produced. At E is a small arch from the top of which a mandrel descends down through the hole. This mandrel is exactly the internal diameter of the pipe. The charge of from 2 to 4 cwt. of molten lead is poured into the space D. and left to solidify. Round the cylinder G H is another cylinder K L of larger diameter, and between these cylinders a fire is kept up for the purpose of preserving the lead at the proper temperature. When this temperature has been reached by the cooling of the molten mass, pressure is applied to the plunger, which descends with great force. The lead is thus forced between the cylindrical hole and the mandrel, like a lump of putty under ordinary pressure, and it issues at the bottom as one continuous pipe. It will be at once seen that an immense length of ordinary pipe is obtainable, without joint, by this process. In practice, however, it is usual to cut the pipe off in lengths of 60 ft. for convenience of stowage and transport. A remarkable fact in this process is that the solid lead which is divided by the arch E joins again below the arch under the influence of the hydraulic pressure without leaving any trace of the division it has undergone.

6382.



Previous to the discovery of this fact, the mandrel was fixed directly into the plunger C, so as to avoid the difficulty of the arch. The latter, being a more convenient arrangement, is now generally adopted.

The tensile strength of lead may be taken as 2745 lbs. to the inch. The thickness of metal to withstand water-pressure is therefore given by the formula $T = \frac{\cdot 433\,H\,R}{2745}$. This thickness should be multiplied by a factor of safety, which, in ordinary cases, may be taken as ten. The weight of lead pipe is found by the formula already given for cast iron, by taking $K = 3\cdot 86$, namely, $K\,(D^2 - d^2)$. The diameter is determined by the quantity to be delivered in a given time under a given head of pressure. In the case of an intermittent water-supply, the diameter should be sufficient to fill the cistern in a space of time considera ly less than the hours during which the water is on.

The action of some kinds of water upon lead pipes is very destructive. This is especially the case with soft water, as calcareous matter stops corrosion at a certain point by forming an insoluble coating. A recent invention provides effectually against the corrosive action of soft water on lead pipes. This is Haine's lead-encased block-tin pipe. By Haine's process, which is similar in its details to that described above, pipes may be manufactured with an inner casing of tin, and the process of manufacture is so perfect that it may be bent and otherwise manipulated with the same facility as lead. These pipes are greatly superior to lead from a sanitary point of view, and they possess considerably greater strength. Experiments to test their quality in this latter respect were made in July, 1871, by means of Kirkaldy's t-sting machine, the result being that Haine's ½-in. pipe, weighing 4·917 lbs. a yard, burst with a pressure of 1859 lbs. to the inch, while a ½-in. common lead, weighing 7·139 lbs., burst with 1579 lbs. pressure. Also, a Haine's 2-in. pipe, weighing 16·406 lbs., burst with a pressure of 642 lbs. to the inch. A common 2-in. lead pipe, weighing 27·967 lbs., has burst with a pressure of 498 lbs. Thus, strength for strength, this kind of pipe is not more expensive than the common kind, while its hygienic advantages render it greatly superior for purposes of water-supply.

Stoneware Pipes.—The materials of which stoneware pipes are made vary with the district in which they are produced, and hence these kinds of pipe are of various qualities, and possess various characteristics. In Staffordshire, for instance, they are burnt from a species of fire-clay, and are dark in colour, being similar in character to the Staffordshire bricks. In London, they are made of clay obtained from various parts, with an admixture of broken pottery finely ground and sifted, while in some parts of Kent gault-clay is chiefly used, producing a pipe light in colour and of very tough consistency. Fire-clay pipes are usually classed distinct from stoneware, and, thickness for thickness, are generally considered as somewhat inferior to the latter in strength. Whatever is the nature of the materials employed, however, they must possess certain qualities. The most important of these qualities, probably, is that of impermeability. If a drain-pipe is made of porous material, it will not long resist the influences that will be brought to act upon it,—such as, for example, the crystallization of water in time of frost, or the formation of crystals in the presence of certain chemical compounds, which are pretty sure to exist in sewage. Moreover, when a pipe becomes saturated with moisture, it is incapable of supporting a great superincumbent weight, and therefore, when laid at a considerable depth beneath the surface, deformation and fracture are likely to occur. To be impervious to moisture, the material should be vitreous in character, having sufficient toughness to resist shocks, tenacious, hard, and homogeneous. Pipes should be burned at a high temperature; they should be uniformly glazed inside and out, and be free from fire-cracks; they should ring clearly when struck, and be uniform in thickness and section. They may be tested for impermeability by drying them till they cease to lose weight, and then placing them in water for twenty-four hours. By reweighing them after they have been carefully wiped, the quantity of water absorbed may be clearly ascertained. This quantity should not exceed 5 or 6 per cent. of the weight of the pipe.

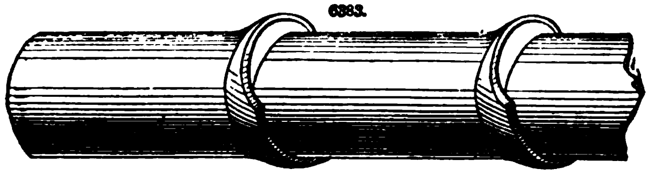
The tensile strength of stoneware pipe varies greatly. Experiments made by Baldwin Latham showed that it might vary from 21·4 lbs. to 429·5 lbs. to the square inch of section. Thus, the thickness requisite for a stoneware pipe is a question to be determined by experience rather than by calculation. When first used for town sewage, they were made insufficiently thick, and hence they failed in many instances, notably at Croydon. But in these cases the failure was due to the inability of the pipes to resist a strain of compression rather than a tensile strain. This indeed is the principal strain brought upon a sewage pipe, and it may be safely assumed that if a pipe is capable of bearing the crushing force brought to bear upon it when laid, it is abundantly capable of withstanding any internal pressure to which it is likely to be subjected. Numerous experiments carried on under the direction of J. W. Bazalgette, showed that the ability of stoneware pipes to resist a crushing force is much less variable than their tensile strength.

The following Table shows the dimensions and thickness now given to stoneware and fire-clay pipes;—

Stoneware.				Fire-clay.			
Internal Diameter.	Thickness.	Length in Work.	Depth of Socket.	Internal Diameter.	Thickness.	Length in Work.	Depth of Socket.
inches.	inches.	feet.	inches.	inches.	inches.	feet.	inches.
3	½	2	1½	3	½	2	1½
4	½	2	1½	4	½	2	1½
6	⅝	2	1¾	6	¾	2	1¾
9	¾	2	2	9	⅞	2	2
10	⅞	2	2	10	1	2	2
12	1	2	2	12	1 1/16	2	2
15	1⅛	2	2¼	15	1¼	2 to 3	2½
18	1¼	2 to 3	2½	18	1½	2 to 3	2½

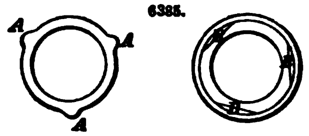
The usual form of sewer-pipe is the plain spigot and socket. The objection to this kind is the difficulty of opening them for examination. To remove this difficulty several modifications have been from time to time introduced. Fig. 6383 represents one of these, in which the upper half of the socket is absent. The object of this arrangement is to allow a single length to be removed and another dropped into its place, without deranging the adjacent pipes. Another form of pipe, known as Jennings' pipe, from the name of the inventor, is shown in Fig. 6384. The inventor in his description says,—"They are plain at both ends, and are laid in chairs similar to the metals of a railway, each pipe being kept 6, 9, or 12 in. apart, according to their diameter. The pipes being bedded in the chairs renders the disturbance of ground under the pipes to make the joints (as at present) unnecessary, and the top part of the chair (which for distinction is called a saddle-piece) being the last fixed, enables the workman and superintendent to see that the pipes are properly laid and fairly jointed. In case of stoppage the saddle is easily removed without in any way disturbing the invert or general drain; and the pipes being some distance apart, the state of the drainage can be easily ascertained." Various other arrangements have been introduced for the purpose of facilitating inspection; but they are all open to the objection that they either weaken the pipe or increase the tendency to leak when running more than half full. Since the introduction of the mode of laying sewers in straight lines on plan, with man-holes or lamp-holes at every change of inclination or direction, the necessity for these kinds of pipe has ceased.

6383.



6384.

6385.



In laying sewer-pipes, the spigot end should be the lower, and great care should be taken to give them a uniform bearing, though to do this effectually a recess should be cut in the floor of the trench to receive the socket. Great care must also be taken in making the joints. The annular space between the spigot and the socket should be filled with clay worked in by a tool, and for additional security a fillet of clay may be laid on outside. Portland cement may be used with advantage where there is much subsoil water. Some engineers prefer to force into the socket several strands of tarred gaskin with a calking tool previous to using the clay or cement. No doubt, great advantages are obtained by this method by preserving the annularity of the joint. With a yielding material like clay, the superincumbent weight of earth speedily destroys this annularity, unless some means are provided for preserving it. Bothams, of Salisbury, is the inventor of an improved socket for preserving the concentricity of th. joint. The spigot end of the pipe is provided with projections A, A, A, Fig. 6385, and the socket with corresponding projections B, B, B. The spigot end is inserted in the socket so that its projections lie within the projections of the socket, and then turned round until the projections of spigot and socket are brought into contact. By this means the concentricity of the joint is preserved.

Sewage-pipes are sometimes made of Portland cement, and this material is by no means unfit for pipes. Instances might be pointed out in which these have been found to be perfectly sound after being in use upwards of twenty years. They are extensively used in Germany, where they bear the effects of a severe climate remarkably well; that they are sufficiently strong is evinced by the fact that in North Prussia they are used under the railway embankments. As might be supposed, these pipes improve with age, and at the end of two or three years they are said to ring, when struck, with a clear metallic sound.

See Drainage. Sewerage. Water-works.

PISTON. Fr., *Piston*; Ger., *Kolben*; Ital., *Stantuffo*; Span., *Embolo*.

A piston is a short cylinder of metal or other solid substance which fits exactly the cavity of a pump or barrel, and works up and down in it alternately. It is used particularly in the steam-engine and in pumps.

PISTON-ROD. Fr., *Tige de piston*; Ger., *Kolbenstange*; Ital., *Asta dello st ntuffo*; Span., *Vástago del émbolo*.

The rod by which the piston is moved, as in a pump, or by which it communicates motion, as in the steam-engine.

PITCH. Fr., *Pas*; Ger., *Theilung*; Ital., *Interasse Passo*; Span., *Entre-eje*.

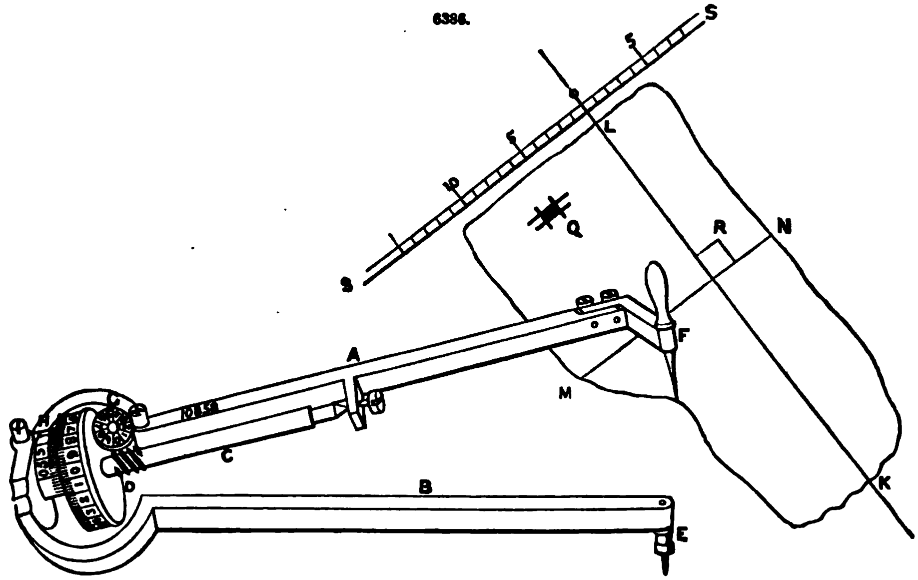
Pitch is the distance from centre to centre of any two adjacent teeth of gearing measured on the pitch line. It is also the distance measured on a line parallel to the axis, between two adjacent threads or convolutions of a screw; and the distance between the centres of holes, as of rivet-holes in boiler-plates.

PLANIMETER. Fr., *Planimètre polaire*; Ger., *Planimeter*; Ital., *Planimetro*; Span. *Planímetro*.

Tho polar-planimeter, Fig. 6386, which for ordinary use is not much larger than a common pair

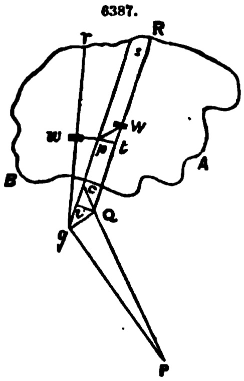
of compasses, measures the area of plain surfaces of any shape by merely following the outline of the figure with a pointed tracer F, the point E remaining stationary. The improved form given to the original instrument of Oppenkofer, by Amsler, possesses many advantages over the forms given to this instrument by Welty and others. The polar-planimeter of Amsler, with its case, weighs about seven ounces, and it can be set to any desired scale of reduction and to any unit of measure. The most simple form is shown in Fig. 6386, which, however, will only suit one scale of reduction

6386.



and one unit of measure; but any desired scale can be obtained by multiplying the result given by the planimeter by a constant factor. The constant factor or multiplier may be found in a few seconds, in any particular case, by passing the tracer F round a square, triangle, or other figure of known area. The index roller D must play easily without coming into contact with the vernier. The screw centres on which the axis of D is revolving must be adjusted so as to allow perfect freedom of rotation; the same is to be observed for the centre pin C. The needle point E should project but very little from its socket, and the point of the tracer F should be so formed as not to catch in the paper. The roller D, which moves on the paper, will not bear the least spot, rust, or the slightest injury, without impairing the accuracy of the instrument. The planimeter may be applied to find very exactly the mean pressure of steam from an indicator diagram card. For example, let K L M N be an indicator diagram card, each of the small divisions on the scale of pressures S S, answering to 2 lbs. = ·093 in.; the length of the stroke L K = 59 in. = 29·5 parts measured on the scale S S. Then $\frac{29\cdot5 \times \cdot093}{59}$ = the length of each inch of stroke on the line K L; let Q be a small parallelogram, whose length = ·093 and breadth = $\frac{29\cdot5 \times \cdot093}{59}$. Now suppose that we find, by passing the point E round the diagram, that the area = 123·48, or equal 123·48 small squares like R, each side of which = ·195 in., which unit of length is also given by the planimeter. Whence, $123\cdot48 \times (\cdot195)^2$ divided by $\frac{29\cdot5 \times (\cdot093)^2}{59}$ gives the exact number of small parallelograms equal and similar to Q, contained in the diagram M L N K. In the example we have taken the number is = 1085 4. Then $\frac{1085\cdot4}{59} = 18\cdot4 =$ M N, $18\cdot4 \times 2 = 56\cdot8$ lbs., the mean pressure.

6387.



To some of our readers it may be important to prove that the principles upon which this ingeniously contrived little instrument is constructed are mathematically correct. The truth of those principles may be established as follows;—Let P Q, Q R, be two bars or rods, Fig. 6387, connected by a joint at Q; suppose the end P to be fixed, while R is passed completely round the periphery of any area A R B; and that on a given point of the bar Q R a wheel W is placed, which turns upon Q R as an axis; the motion of the rods P Q, Q R, being always in a plane parallel to the plane of the paper. Let P q, q r, and w be the consecutive positions of, and extremely near P Q, Q R, and W.

Let $\pi = 3\ 14159265\ .\ .\ .$ P Q $= a$, Q R $= b$, Q W $= c$; and the angle P Q R $= \pi - \theta$; the angle C Q R = Q C $v = \theta$, Q v is supposed to be drawn perpendicular to q C. Put x = the angle described by P Q from its initial position, and y = the angle described

by Q R in moving from its initial position; and put S for the space described in the same time by any point of the wheel W, in turning on its axis, the sliding motion not being taken into account. Then if z be the area of the irregular figure A R B,

$$
\begin{aligned}
dz &= \text{the sum of the areas } \mathrm{P\,Q}\,q,\ \mathrm{Q}\,q\,s\,\mathrm{R},\ s\,q\,r; \\
&= \tfrac{1}{2}a^2\,dx + q\,s \times \mathrm{Q}\,v + \tfrac{1}{2}b^2\,dy; \\
&= \tfrac{1}{2}a^2\,dx + b\,(\mathrm{Q}\,q \cos.\,\theta) + \tfrac{1}{2}b^2\,dy.
\end{aligned}
$$

$$
\begin{aligned}
\text{But } d\mathrm{S} &= w\,p + p\,t = c\,dy + q\,\mathrm{Q}\cos.\,\theta, \text{ or} \\
q\,\mathrm{Q}\cos.\,\theta &= d\mathrm{S} - c\,dy; \\
\therefore\quad dz &= \tfrac{1}{2}a^2\,dx + b\,(d\mathrm{S} - c\,dy) + \tfrac{1}{2}b^2\,dy \\
\therefore\quad z &= \tfrac{1}{2}a^2 x + b\mathrm{S} + b\,(\tfrac{1}{2}b - c)\,y,
\end{aligned}
$$

it is evident that when R has passed round the irregular figure $x = o$ and $y = o$, and hence x and y vanish; consequently $z = b\,\mathrm{S}$.

If the fixed point P be taken within the figure A R B, then it is evident that the rods will completely pass round the point P, therefore the limits of x are o and 2π, which are also the limits of y, and z becomes $b\,\mathrm{S} + \pi\,(a^2 + b^2 - 2\,b\,c)$. Hence we have proved that if P be fixed while R is moved round the periphery of any area, the amount of rotation of the wheel W, without regard to its sliding, will be proportional to the area.

See INDICATOR.

PLANING MACHINE. FR., *Machine à raboter;* GER., *Hobelmaschine;* ITAL., *Pialla da metalli;* SPAN., *Máquina de cepillar.*

See MACHINE TOOLS.

PLATE-WHEEL. FR., *Roue à disque;* GER., *Scheibenrad;* ITAL., *Ruota di lamiera;* SPAN., *Rueda llena*

A wheel whose pin is connected with the axle by a thin plate of metal instead of arms.

PLATIN. FR., *Platine;* GER., *Tiegel;* ITAL., *Tavola mobile,* SPAN., *Platina.*

The platin or platen is the movable seat of a machine tool on which the work is secured, or in a printing press, the flat part of the press by which the impression is made; called also table and carriage. See MACHINE TOOLS. PRESS.

PLATINUM. FR., *Platine;* GER., *Platin;* ITAL., *Platina,* SPAN., *Platina.*

Until very recently, the metallurgical treatment of platinum was by the wet way. The ore was freed by mechanical means of any earth that might be adhering to it, and then acted upon by aqua regalis, which dissolved the platinum, and a little iridium. The liquor was then decanted. evaporated till nearly dry, and precipitated by a concentrated solution of chloride of ammonium. The precipitate of double chloride of ammonium and platinum thus produced was washed in alcoholized water, and then calcined. A spongy mass of platinum was the result of these operations, which mass was rubbed to a powder by hand, and afterwards made into a paste with water. This paste, when subjected to intense pressure in an iron cylinder, gave a metallic mass of a certain consistency, which was then heated to a red heat and hammered on its ends to render it homogeneous and ductile. If hammered on its sides it splits.

In 1861 M. Deville published a very important work on the metallurgy of platinum, in which work he substitutes the dry for the wet way. A hundred parts of the ore, freed of its impurities by mechanical means, are fused with an equal weight of galena, sulphuret of lead, the iron contained in the ore unites with the sulphur of the galena, and the platinum unites with the lead thus liberated. Fifty parts of lead are then added to the molten mass, which is afterwards further treated and stirred until no resisting grains are felt. The temperature during this operation must reach at least the point of fusion for gold, and may rise above that point without injury When this point of the operation is reached, air is blown into the crucible, the sulphur passes into the state of a sulphurous anhydride and liberates itself, and a portion of the galena passes into the state of lead, and combines with the platiniferous alloy, at the same time the iron and copper, which were in the state of sulphuret, collect as a scum of oxides on the surface of the bath. As soon as the liberation of sulphurous anhydride ceases, two parts of binoxide of manganese and about ten parts of glass are added, forming a fusible slag containing the manganese, iron, copper, and glass, and a metallic mass. This is then left to cool, and when ready, the crucible is broken, and the alloy of platinum and lead, which readily separates from the slag, is taken out. This alloy is next placed in a cupel resting above a crucible full of coke, and having its bottom pierced with an aperture. Crucible and cupel are then heated in a muffle, when the lead becomes oxidized and passes into the state of litharge. This latter fuses, filters through the pores of the cupel, which is made of bone-ash, and falls upon the coke; there it is reduced, and metallic lead remains, which flows out through the aperture in the bottom of the crucible This operation is known as cupellation. The platinum thus obtained still contains a few hundredth parts of lead, a little osmium, some iridium and rhodium. To remove these, it is placed in a small furnace of lime, which substance is employed on account of its being a bad conductor of heat, and melted by means of the oxyhydrogen blow-pipe; it is kept in a state of fusion until neither vapour of lead nor smell of osmium is evolved.

Platinum obtained by the means just described contains iridium, and even rhodium, but this alloy is superior to the pure metal for ordinary uses. If it be required to obtain the metal perfectly pure, the platinum of commerce must be dissolved in aqua regia, and lime added while protected from the light. The iridium is precipitated in the state of oxide; the solution being then filtered, the platinum is precipitated by means of chloride of ammonium. The precipitate being washed and calcined, there remains spongy platinum, which may be employed in this state to prepare the various platinic compounds.

Platinum may also be obtained under the form of a black powder called platinum black, by heating an alcoholic solution of potash with bichloride of platinum until effervescence ceases. The

black powder precipitated is afterwards washed in alcohol, hydrochloric acid, potash, and, lastly. water.

Platinum is a bright white metal, approaching silver in appearance. It occupies the third rank for ductility, and the fifth for malleability. A platinum wire ·078 in. in diameter breaks with a weight of about 270 lbs. It is harder than silver, but not so hard as copper and iron; iridium increases its hardness. Its specific gravity is 21·15; atomic weight, 197; molecular weight, unknown. In several of its compounds it is isomorphous with iridium and osmium.

A remarkable feature of platinum is its great infusibility, melting only before the oxyhydrogen blow-pipe; when at a red heat, it is weldable like iron. It is unaffected by atmospheric influence, and does not undergo oxidation in the air at even the highest temperatures. It is not acted upon by nitric acid unless allied with silver, nor, indeed, by any acid; but in aqua regia it slowly dissolves, and forms a soluble bichloride. Potash and lithia, however, produce oxidation, and a fusible alkaline platinate is formed. With nitrate of potash this oxidation is more rapid; soda does not affect it so readily as the other two alkalies. Bisulphate of potash also attacks platinum when heated. Bromine and iodine do not act upon it, but chlorine combines with it slowly. Phosphorus and arsenic also combine with it when heated, and form a fusible phosphoride and arseniate. When a phosphorated organic matter is heated in a platinum crucible, the latter is quickly destroyed by the liberated phosphorus. Sulphur may also combine with platinum by means of heat if the metal is in the spongy state. In the presence of carbon, silica converts platinum into a fusible siliciide; therefore a crucible of this metal should never be heated directly in a coal fire, as the silica contained in the coal would destroy the crucible. Platinum in a very comminuted state unites with mercury; an amalgam of this metal may be obtained by reducing a platinic compound by means of electricity in the presence of mercury.

When in the state of spongy platinum or platinum black, this metal possesses a remarkable power of condensing and absorbing gases, one volume of platinum black being able to absorb more than 100 volumes of oxygen. This absorption appears to be accompanied by a conversion of some or all of the oxygen into the modification known as oxone, since the metal becomes capable of exerting the most energetic oxidizing action, even at ordinary temperatures. It is capable of causing the combustion of a jet of hydrogen, and it is largely employed to produce oxidation in various substances.

Platinum is tetratomic, and forms two series of compounds, in the first of which it occurs with a value of substitution equal to two, and in the second it has its greatest capacity of saturation. Thus there exist a protochloride of platinum, $\mathrm{Pt\,Cl_2}$; a bichloride, $\mathrm{Pt\,Cl_4}$; a bibromide, $\mathrm{Pt\,Br_4}$; a protoiodide, $\mathrm{Pt\,I_2}$; and a biiodide, $\mathrm{Pt\,I_4}$. The perchloride and the perbromide of platinum may unite with the alkaline chlorides, bromides and iodides, thus giving double chlorides, the formula of which is, $\mathrm{Pt\,Cl_4,\,2\,M\,Cl}$. The bichloride of platinum is obtained by dissolving the metal in aqua regia, and evaporating to get rid of the excess of acid. This bichloride dissolves readily in water, alcohol, and ether; it fuses when heated, and if subjected to a higher temperature than that required for fusion, it is first decomposed into chlorine and protochloride, and afterwards into chlorine and platinum. The double salts which it forms with the alkaline chlorides are nearly insoluble in water and insoluble in alcohol. At a red heat they are decomposed into alkaline chloride, platinum, and chlorine. The double chloride of platinum and ammonium leaves a residue of platinum only, on account of the volatile nature of ammonic chloride.

There exist also two sulphides of platinum, a protosulphide, $\mathrm{Pt\,S}$, and a bisulphide, $\mathrm{Pt\,S_2}$; these are obtained by double decomposition, by acting upon the corresponding chlorides with hydrosulphuric acid.

$\mathrm{Pt\,Cl_4}$	+	$2\left(\begin{matrix}\mathrm{H}\\ \mathrm{H}\end{matrix}\right\}\mathrm{S}\Big)$	=	$4\left(\begin{matrix}\mathrm{H}\\ \mathrm{Cl}\end{matrix}\right\}\Big)$	+	$\mathrm{Pt\,S_2}$
Perchloride of platinum.		Hydrosulphuric acid.		Hydrochloric acid.		Bisulphate of platinum.

These sulphides dissolve in the alkaline sulphates, and act therefore as acid anhydro sulphides.

Two oxides of platinum are also known corresponding to the two sulphides, the protoxide $\mathrm{Pt}\,\Theta$, and the binoxide $\mathrm{Pt}\,\Theta_2$. The former is obtained by the action of potash upon the protochloride, and the latter by the action of the same alkali upon the bichloride; but these oxides being soluble in the alkalies, the solution must be afterwards precipitated by an acid. To each of these oxides corresponds a hydrate; that corresponding to the protoxide has not been analyzed, but its probable formula is $\left.\begin{matrix}\mathrm{Pt}\\ \mathrm{H_2}\end{matrix}\right\}\Theta_2$; the formula of the hydrate corresponding to the binoxide is $\left.\begin{matrix}\mathrm{Pt}\\ \mathrm{H_4}\end{matrix}\right\}\Theta_4$. The hydrogen typical of these hydrates may be replaced, either by acid radicals, in which case salts of platinum are formed, or by alkaline metals, when platinates are produced. These hydrates are therefore as much acids as basics, and their anhydrides must be considered as indifferent oxides.

Reactions of the Salts of Platinum.—The following are the characteristics of the salts of platinum;—

1. Hydrochloric acid does not precipitate them.
2. Hydrosulphuric acid produces with them a precipitate soluble in the alkaline sulphurets, insoluble in hydrochloric and nitric acid employed separately, and soluble in aqua regia.
3. In liquors not too dilute, chloride of ammonium and chloride of potassium produce yellow precipitates; and even in very dilute liquors the precipitate is formed if a little alcohol has been added.

PONCELET'S WATER-WHEEL. Fr., *Roue hydraulique de Poncelet;* Ger., *Poncelets Wasserrad;* Ital., *Ruota alla Poncelet;* Span., *Rueda Poncelet.*

See Hydraulic Machines.

PRESS. Fr., *Presse;* Ger., *Presse;* Ital., *Torchio;* Span., *Prensa.*

Printing Presses.—Fig. 6388 is a front view. Fig. 6389 a side elevation of a Gordon press, as made by Harrild and Sons, of London; and Fig. 6390 a sectional view, showing some of the working parts.

In this machine the form of type *a*, *a*, is placed in a vertical or nearly vertical position, and is held in place on the bed-plate *b* of the machine by means of a spring clip or weighted catch *c*,

6388.

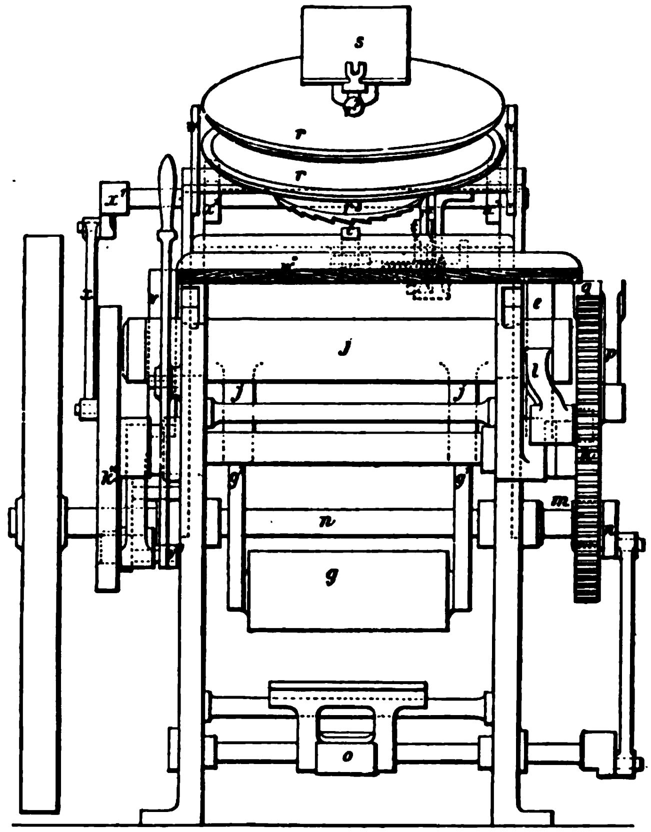


Fig 6389, so that the form *a* can easily be removed and replaced by merely throwing back the catch and lifting out the form.

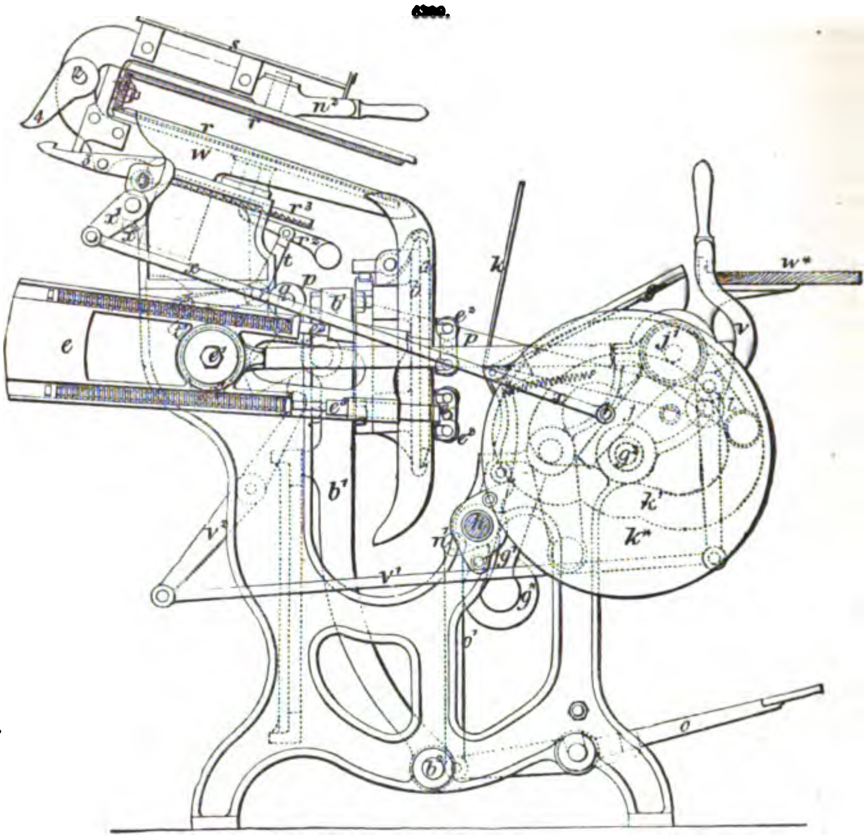
The form, secured in a suitable chase and mounted on the bed-plate *b* of the machine, requires only a very slight forward motion to bring it into position to impart the impression to the paper. To this end the bed-plate *b* is mounted on a lever or arm b^1, which works on a rocking shaft b^2, so that it may be moved forward at the proper time for giving the impression to the paper. This forward motion is given by a cam-piece *d*, Fig. 6390, on the rocking shaft e^1 of the inking-roller frame *e*, *e*, *e*, coming against a knuckle-lever *f*, at the back of the form-frame and bed-plate *b*. When these two parts *d* and *f* come together the bed-plate *b* with the form *a* thereon will be thrust forward about half an inch, which is sufficient to bring it into position to give the impression to the paper when the latter is brought down by the platen *g*, which is provided with a frisket *h* to hold the paper down. The platen *g* is mounted on a vibrating frame g^1, g^1, which as it rocks on its centre of motion g^2 will bring the platen *g* forward, and downward, and opposite to the form of type, as shown in Fig. 6390. The platen frame is mounted on the shaft g^2 as its centre of motion, and is counterbalanced by a heavy weight g^4 on its lower arm.

The thrust on the platen *g* is taken by a pair of vibrating arms *j*, *j*, forming part of a shaft j^1, which extends across the machine, and on the same shaft is fixed a lever *l*, provided at its end with a pin working in a cam-groove k^1 in the cam-plate *k*. The cam-plate *k* is provided on its periphery with teeth into which gear the teeth of a pinion *m* on one end of the main shaft *n*, which is actuated by means of the treadle-lever *o*, the connecting rod o^1, and the crank n^1 on the end of the shaft *n*. As the cam-plate *k* rotates the cam-groove k^1 acts on the lever *l*, and thereby moves the shaft j^1 on its axis, and brings up the vibrating arms *j*, *j*, into the horizontal position shown in Fig. 6390, so that their outer ends will be brought opposite to projecting pieces g^3 on the back of the platen.

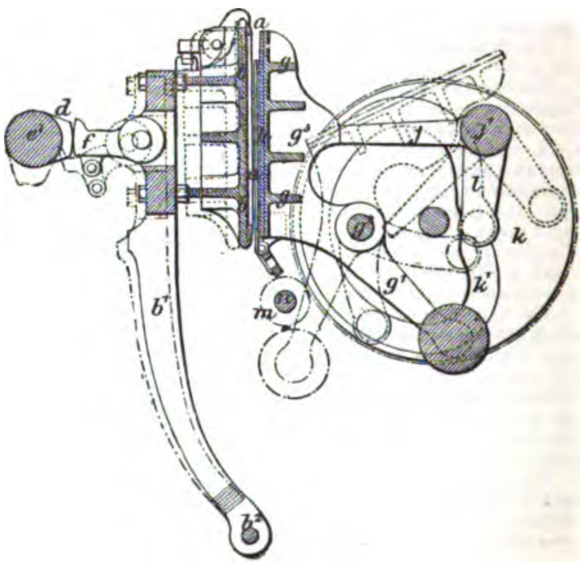
The inking rollers e^2, e^2, are mounted in bearings at the ends of the spring rods e^3, e^3, which work in one swinging frame *e* mounted on the shaft e^1, behind the vibrating form-frame *b*. The swinging inking frames *e*, *e*, are keyed on to the rocking shaft e^1, on the outer end of which is a crank-arm or lever *q*, which is connected by a link *p* to a crank-pin fixed on the face of the cam-plate *k*, so that as this latter rotates in the direction of the arrow in Fig. 6389, the link *p* will push back the crank-arm *q*, and thus cause the inking frame *e*, *e*, to swing on its centre of motion e^1, and carry the inking rollers e^2, e^2, up to and over the surface of the type in the form *a*, to the movable

distributing surfaces r, r, above. These surfaces are in the form of circular discs, to which rotary motion on their vertical axes is given by means of a pawl r^2, acting on a circular ratchet rack r^3,

6389.



6390



mounted on the axle of the circular disc r. The pawl r^2 is mounted at the upper end of a bell-crank lever t, the other arm of which is acted on by a cam t^1, shown by dots in Fig. 6389, mounted on the shaft e^1, so that as the latter rotates and causes the swinging inking frame e to carry the inking rollers e^2 up over the surface of the form of type the circular distributing surfaces are made to move round a few inches on their centre of motion.

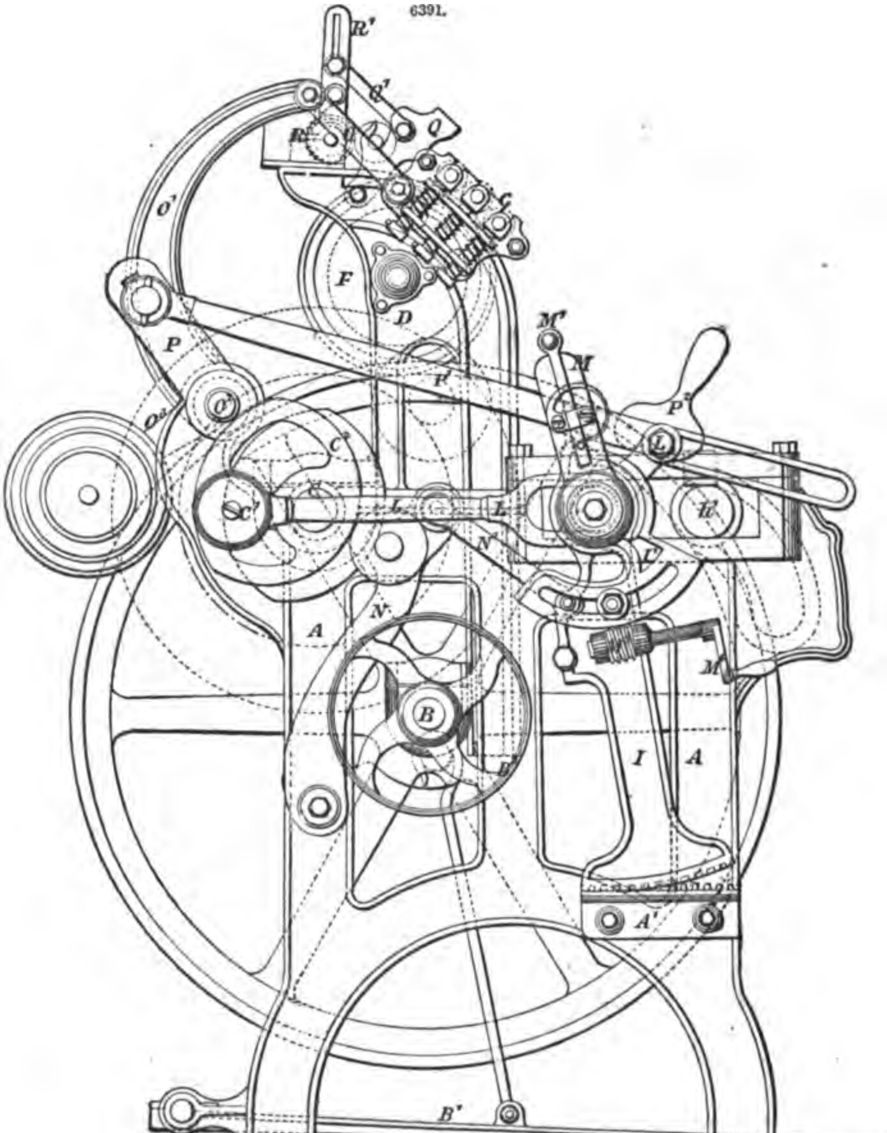
For light work an ink fountain will not be required, as but a small quantity of ink will be used on the job. A sufficient quantity for a small job may be placed on a fixed plate s situated above the rotating distributing surfaces r, r, and these latter may be supplied from time to time by means of a small hand-roller.

The two distributing discs r, r, are geared together by the wheel u, so that they will rotate in opposite directions, and the inking rollers e^2, e^2, in advancing will rotate in contact with one disc, that is to say, the lower one as they run along the guides w, w, and in retreating they will be lifted up by the guides w, and will rotate in contact with the other or upper disc. This lifting motion of the guides w is effected by

means of a stud-pin 1, fixed on the face of the cam-plate k, which by means of the rod or link x will draw down an arm x^1, on the axle of which is a snail x^2, which by bearing against a bowle on the frame of the guides w, w, will lift up the latter and thus cause the inking rollers to rotate in contact with the upper disc.

To obtain access to the double distributing surface the upper disc r is mounted in a movable frame which is capable of being lifted up on the centre pin 2 by the handle r^2. When raised it may be held in the elevated position by the catch 3 which will lay hold of the tail 4 of the upper frame. The attendant may then supply more ink by means of his roller, as already explained.

6391.

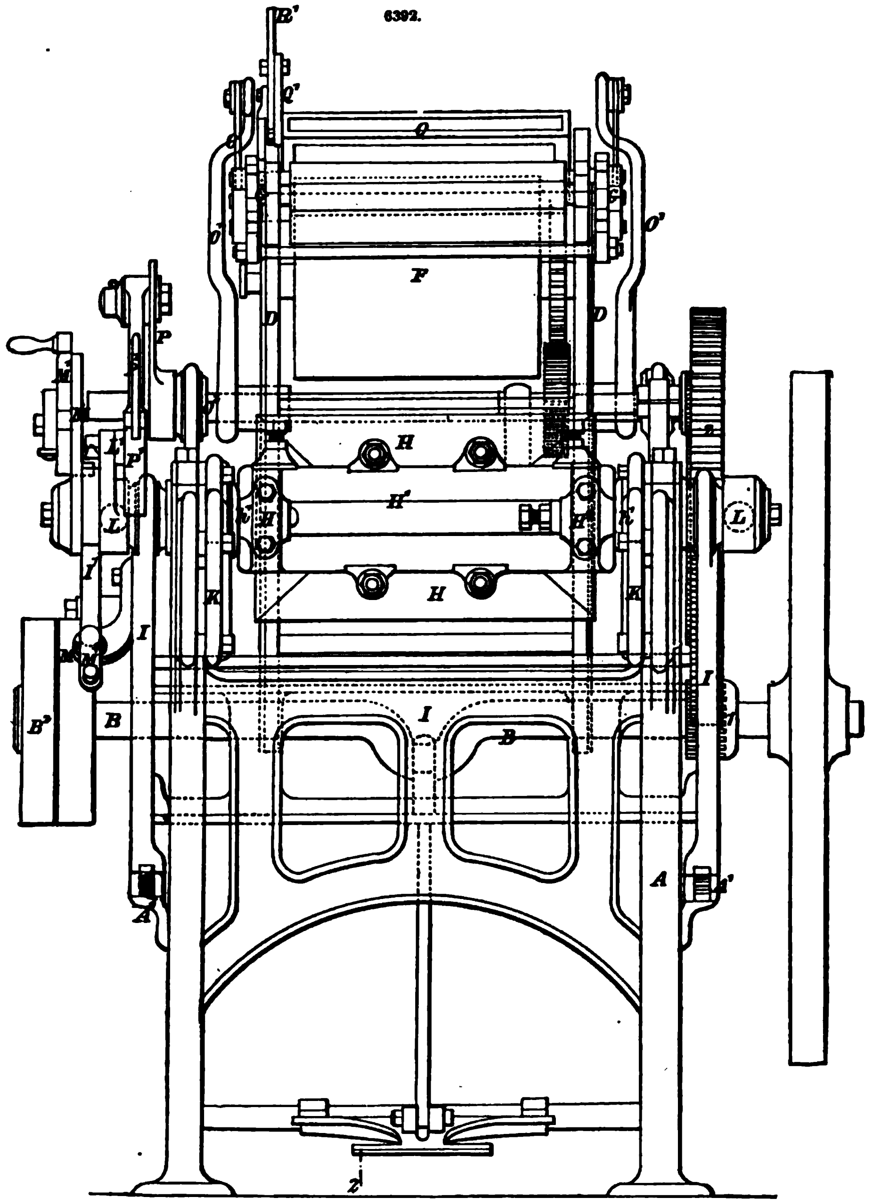


In order to throw the machine out of gear and prevent the form of type from printing, although some of the parts may be in motion, a hand-lever v is connected by a link v^1 to a stop-lever v^2, which when acted upon will lift up the knuckle-joint f, at the back of the vibrating form-frame b, so as to prevent the cam-piece d on the vibrating shaft e^1 from coming against it and driving forward the form a. This arrangement will be found very convenient when the machine is to be driven by power.

Fig. 6391 is a side elevation; Fig. 6392 is a front elevation; and Fig. 6393 a vertical section

taken in the line 1, 2, of Fig. 6392, of an ingenious modification of the Gordon press, designed by William Carwood, and of which Hopkinson and Cope, London, are the makers.

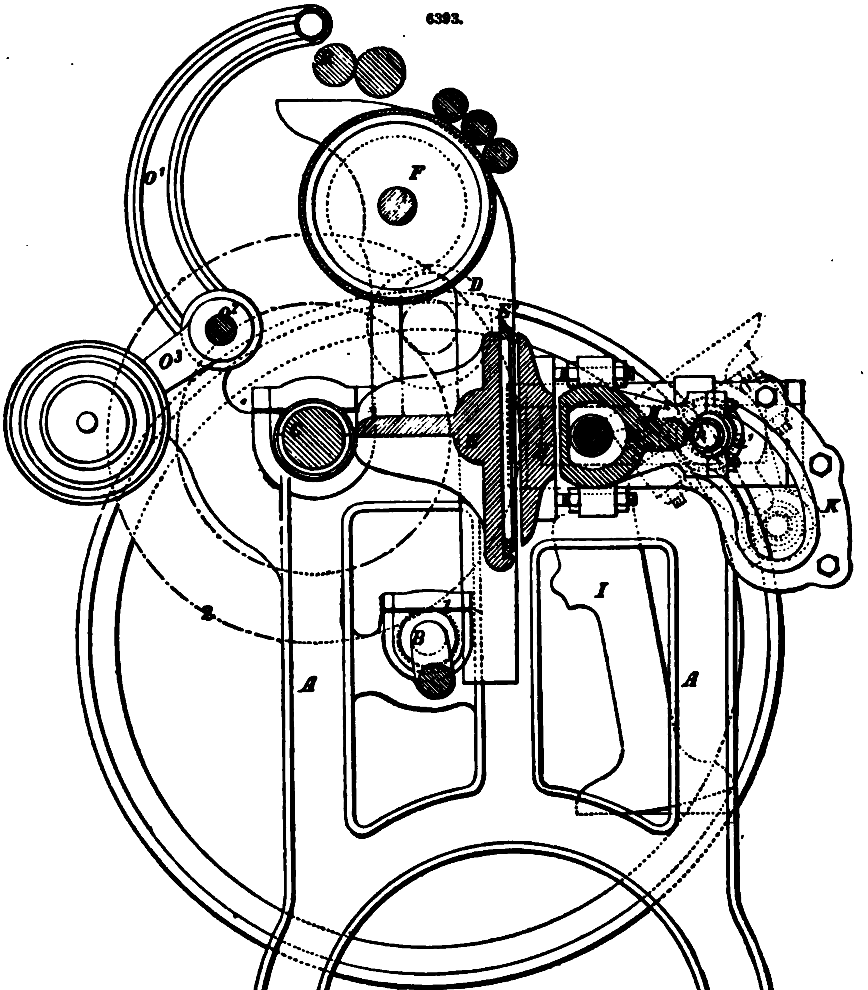
6392.



A A is the main framing, supporting in bearings a driving shaft B, which may be worked by a treadle B^1 or by a band from any prime mover working over the band-pulley B^2. Keyed to this driving shaft B is a spur-pinion 1, which gears into and drives a spur-wheel 2 on the main shaft C, running in bearings at the back of the frame A. This frame A carries within it standards D, D, to which is affixed the vertical bed E of the press, and near the top of the standards is mounted the ink distributor F. These standards D form guides for an inking-roller carriage G, the rollers of which take up ink from the distributor and passing down the standards impart ink to the type, which is secured to the bed E by means of the type frame E^1. Immediately opposite the type frame is mounted the platen H, bolted to a sliding tipping block H^1, provided at its rear with a pair of arms H^2. These arms each carry a stud-pin h, and mounted loosely on each stud-pin is a flanged bowle h^1 for the purpose to be presently explained. The tipping block H^1 is made hollow to receive a horizontal shaft H^3 fitted therein so as to turn as in bearings. The ends of the shaft are slightly eccentric to the main body, and they are supported in bearings formed by sliding blocks

which work between parallel horizontal guides formed in the upper part of the framing A. The ends of the shaft H^2 project through their bearings, through the sliding blocks, and through the upper frames of a rocking frame I, external of the framing A. This rocking frame is supported on horizontal bracket-pieces A^1 bolted to the frame A, and furnished with rack teeth, and the lower ends of the framing I are segment-shaped, the segment being struck from the axis of the shaft H^2, and furnished with teeth which gear into the racks of the bracket-pieces A^1. This arrangement ensures that the axis of the platen-shaft shall on the advance of the platen to give the impress, be always in the same horizontal plane.

6393.



For the proper operation of the machine it is requisite to give to the platen H not only a traverse motion to and from the type, but also a tipping motion when it is withdrawn from the type, in order that the impressed sheet may be readily removed and a fresh sheet supplied thereto. It is for this purpose that the block H^1, which carries the platen, is made free to rock on its shaft H^2. To ensure this tipping motion curved guides K, K, are provided. These guides are made fast by means of bolts to corresponding projecting pieces on the frame A, and in the curved grooves of these guides the before-mentioned flanged rollers h^1 run. Thus as the platen is withdrawn from the type it will, by the running of these rollers down their curved guides, be tipped into the inclined position, Fig. 6393, ready to have the printed sheet removed and to receive a fresh sheet of paper.

The traverse motion of the platen is obtained by the throw of a pair of crank-pins C^1 acting

on it through a pair of link rods. One of these crank-pins projects from a cam C^2, keyed to the main shaft C, and the other from the spur-wheel 2. These crank-pins C^1 are embraced by straps of the link rods L, the other ends of which embrace the ends of the shaft H^3, thus allowing the link rods to move a considerable distance without acting upon that shaft. The object of this arrangement is to give the platen a dwell when it has attained the position for receiving the paper.

To prevent the platen from coming up close to the type, in order to protect the setting-off sheet from being inked, the ends of the shaft embraced by the slotted links are made eccentric. By giving a slight axial motion to this shaft in one direction the platen may be prevented from reaching the type to the extent, say, of an eighth of an inch, and consequently will not give any impression, and by turning the shaft in the opposite direction the pressure of the platen may be increased as desired. This movement of the shaft is effected by means of an arm M made fast to it. This arm carries a spring bolt M^1, which enters a notch in an adjustable segment-shaped plate I^1 through which the shaft passes, and which forms virtually a part of a rocking frame I. This plate is furnished on its lower edge with teeth, which gear into a worm M^3 mounted on the rocking frame I, and capable of being rotated by a winch-handle M^4. The segment-shaped plate is made fast to the frame I by a clamping nut, but when this is slackened it may be adjusted axially by the worm M^3, so as to bring the notch into which the spring bolt enters into any desired position for locking the eccentric platen-shaft. By disengaging the spring bolt and pulling back the lever M, which the attendant can do in an instant, the platen will be prevented from reaching the type at the greatest back-throw of the crank-pins C^1, and the platen may as quickly be re-adjusted for work. To prevent the link rods from striking the shaft H^3 when making their return stroke, an independent means of moving back the platen is provided. This consists of a rock lever N having its fulcrum on the frame A, and connected at its free end by a link rod N^1 to the rocking frame I. This rock lever is fitted with an anti-friction bowle, against which a cam C^3 works. The cut of this cam, Fig. 6391, is such as to press forward the rocking frame I in advance of the return motion of the link rods L, and thus prevent the link rods from coming suddenly into action on the platen-shaft.

The traverse motion of the inking-roller carriage G is obtained by means of its connection by links O with a pair of rocking arms O^1, keyed to a transverse rock shaft O^2 mounted in brackets at the back of the framing A. Keyed also to this rock shaft is a weighted lever O^3, which, acting as a counterweight, tends to return the carriage to or maintain it at the elevated position of Fig. 6391. P is an arm keyed to one end of the rock shaft O^2, carrying a stud-pin for receiving a connecting rod P^1. This rod has at its free end an elongated slot for receiving a pin L^1, which is carried by an extension of one of the connecting link rods L. The rod P^1 is provided with a tumbling claw P^2, which is intended to drop over the stud-pin L^1, and thereby connect the rods L and P^1 together. Through this connection the throw of this crank-pin C^1, Fig. 6391, will cause the rod P^1 to pull over the rocking arms O^1 as the platen recedes from the type, and to move down the inking-roller carriage over the type and ink its surface.

On the return motion of the platen the crank-pin C^1 will, through the link rod L and stud-pin L^1, force back the rocking arms O^1 to the position of Fig. 6391, and so lift the inking-roller carriage and pass it over the ink-distributing roller. The carriage in returning to its quiescent position will strike a rocking frame Q mounted on the standard D and carrying the vibrator inking roller. This action will throw that roller into contact with the fountain roller R, and cause the latter to impart a fresh supply of ink. The rocking frame Q connects by a link Q^1 with an arm R^1 that carries a pawl for operating through a ratchet-wheel the fountain roller in the usual manner.

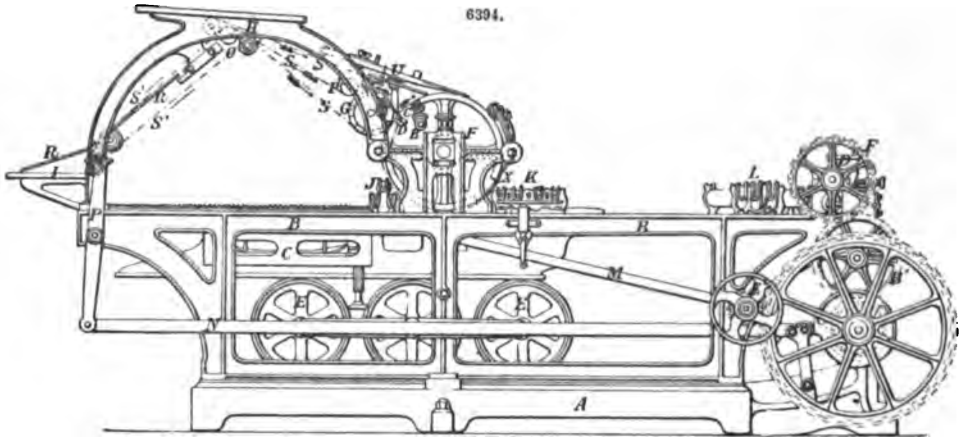
It will be understood that, on the return motion of the carriage G the rocking frame Q will be free to fall back to its depressed position, and bring its roller now charged with ink into contact with the distributor F, which will then in due course impart the same to the rollers of the inking carriage.

When it is desired to increase the supply to the inking rollers they may be left in contact with the distributor while that is still rotating, so as to accumulate ink on their surfaces, by simply tripping up the tumbling claw P^2, which will disconnect rods L and P^1, and thus leave the latter still while the former is being moved by its crank-pin, the pin L^1 being left free to slide in the elongated slot of the rod P^1. In like manner if it is required to pass the inking rollers two or more times over the type before taking off an impression, that can be readily done by maintaining the connection between the rods L and P^1, and turning the platen-shaft H^3 so as to keep the platen out of action by the means above explained.

An excellent lithographic power press by A. H. Marinoni and F. N. Chaudré, is shown Figs. 6394 to 6396. A is the lower framing on which the various parts of the apparatus are mounted; B, side frames, supporting the whole of the driving mechanism; C, carriage, carrying the movable plate on which is mounted the lithographic stones or type; D, screws, serving to regulate the height of the plate or movable plane; E, E, wheels or rollers, carrying carriage C; F, printing cylinder; G, small cylinder, provided with grippers, serving to take the sheet from the printing cylinder and to convey it on the tapes; H, curved frame, carrying the gauging tables, the rollers, and tapes, the mechanical receiver, and other parts; I, receiving table; J, supports of damping rollers; K, supports of inking rollers; L, supports of distributing rollers; M, rod serving to stop the printing roller; N, principal horizontal connecting rod, having a friction roller at one end and serving to transmit the motion to the mechanical receiver; O, eccentric or cam, operating connecting rod N; P, lever, having a toothed segment actuating the shaft of the receiver; R, combination of wood laths or plates, mounted on an iron shaft, serving to invert the printed sheet on the receiving table; S, S, tapes for conducting the sheet; T, small wood table on which the plates R rest in readiness to receive the sheet; A^1, large toothed wheel, mounted on the shaft carrying the eccentrics for stopping the cylinder, the eccentric regulating the receiver and the crank which actuates the plate-holding carriage; B^1, intermediate wheel, governing wheel F^1 of the inking

cylinder, D^1, ink reservoir; E^1, fast and loose pulleys, mounted on the pinion-shaft, driving the whole apparatus by any suitable power. This machine may also be arranged to be driven by hand.

6394.



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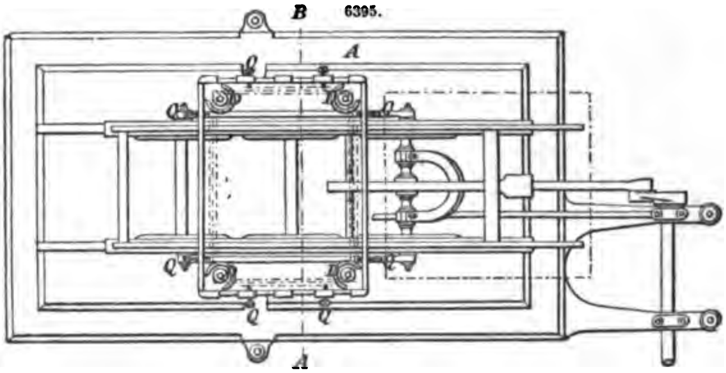
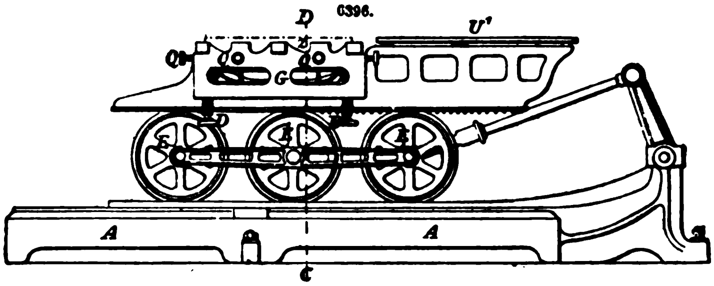


6396.



A, Fig. 6395, is the lower framing of the machine, showing the ways on which run the wheels carrying the carriage, the latter being provided with a plate serving to receive the lithographic stone. This plate, which is commonly termed the slab, is regulated in position in an upward and downward direction by screws D, Figs. 6394, 6396, and sideways by screws Q, Fig. 6395.

A, Fig. 6396, frame of the machine seen longitudinally; E, E, wheels on which the carriage Q^1 is mounted, also showing screws D, and Q Q, serving to fix and hold the plate carrying the lithographic stone or type Z, and section of the metal table U^1 for receiving and distributing the ink on the rollers.

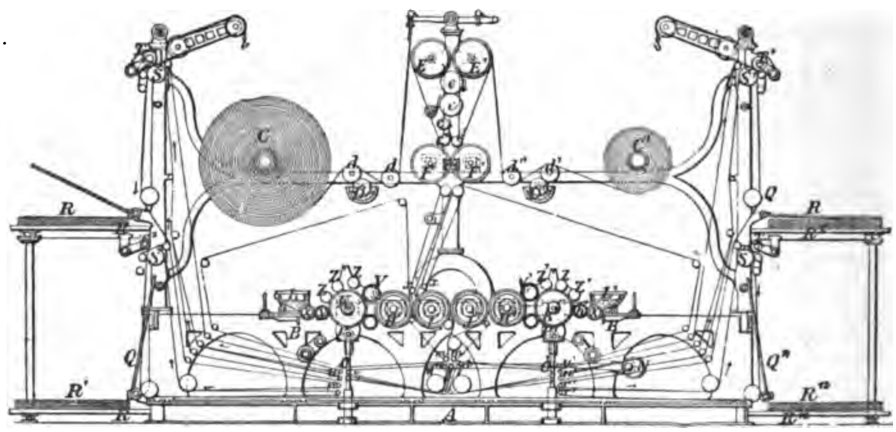
F, Fig. 6394, is the printing roller; G, cylinder of smaller diameter, turning in an opposite direction, but at same speed as cylinder F, and serving to change the direction of the sheet. These two cylinders are each furnished with two shafts B, B^1, C, C^1, those marked B, B^1, having each at the one end a toothed segment, and also furnished with a spiral spring; the shafts C, C^1, are also toothed and gear with B, B^1, being further furnished with a series of grippers for seizing the paper sheet and pressing it on the small supports D, D^1, faced with india-rubber, which are mounted on a rod in the interior of each cylinder. One of these supports in cylinder F bears fixed points not shown in the drawing, while on the other end of the shafts C, C^1, is a small crank furnished with a

friction roller, which in coming in contact with cams mounted on the side frames opens or closes the grippers when desired; U, gauging table or plate, under which is placed the lever carrying the movable plate, the upper surface of the table being furnished with gauges. The parts for actuating the lever of the movable pointers, and those for bringing down the grippers of the printing cylinder, as also other parts not necessary for the elucidation of these improvements, are omitted in the illustrations, being the same as in ordinary printing machines.

The sheet of paper is placed on the table U, between the gauges which guide it on the sides and at front and back, up to the moment when it is seized by the grippers of shaft C of cylinder F and pressed on the india-rubber faced supports D; the cylinder carries round the sheet, which is only held on its edge by the grippers, and at front and back by a series of metal plates X, which secure it on the cylinder without the aid of tapes. When the cylinder F has completed a certain part of its revolution, and the grippers still holding the sheet have arrived at point R^1, the grippers C^1 of cylinder G are quickly brought down so as to grip the sheet, while it is also released from grippers C. The cylinder G carries the sheet round to point P^1, where the grippers of the shaft C^1 open in order to allow it to pass on to the tapes S, S, on which it is conducted to point O^1, when it falls on to tapes S^1, which convey it to the plates of receiver R, in order to reverse it on the table, where all the sheets are deposited after being printed.

Fig. 6397 is of A. H. Marinoni's rotary perfecting press printing from the continuous roll. In this press the continuous paper is cut up into sheets of any desired length before printing, and is delivered by mechanical means at four or more points, the difficulty in delivering the sheets in continuous paper printing machines being thus obviated. The paper being cut up in the machine itself before being printed, the size of the sheet may be altered without changing the cylinders, it being simply necessary to retard the feed of the paper roll in order to diminish the length of the sheet.

6397.



Dividers are employed, which conduct the sheet to the four mechanical arms or flyers, where they are divided in the longitudinal direction of the machine after printing, having been divided in the transverse direction before printing, as above mentioned.

In Fig. 6397, which is a front view of the entire machine, A is the bed; B, side frames; C, C^1, rolls of continuous paper; D, D^1, dampers; E, E^1, e, e^1, drums and rollers for drawing off the paper; F, F^1, cylinders for cutting it up into sheets. There are drums which conduct the said sheets to the blanket cylinders J, J^1, to be printed on both sides by the plates on cylinders H, H^1; K, K^1, cylindrical inking tables; L, L^1, ink fountains; M, first apparatus for dividing the sheets placed at the centre of the machine; N, eccentric, by which the same is operated; O, O^1, second sheet-dividing apparatus, placed towards either side of the machine; P, P^1, eccentrics for operating the same; Q, Q^1, mechanical flyers or receivers; R, R^1, tables for receiving the printed sheets; S, S^1, rollers, at which the sheets are delivered from the machine; T, T^1, knives; X, X^1, ductor rollers; Y, Y^1, vibrators or transferring rollers; Z, Z^1, distributing rollers; V, V^1, inking rollers.

The machine is arranged to receive two rolls of continuous paper, so that whilst one is in use another may be supplied to replace it when exhausted. The rolls of paper coiled on spindles are placed on the machine at C, C^1, and in unwinding the paper is passed over one of the dampers D or D^1, and then between rollers E, E^1, from which point it takes exactly the same course, whether coming from C or C^1, so that it will suffice to describe the action of the machine with reference to one roll, the other operating in an exactly similar manner. For example, the paper from roll C first passes over a roller d, turning by contact with a roller D immersed in a trough containing water. The water is taken off roller D by the small roller d, and deposited on the paper for the purpose of damping it. The paper thence passes under roller d, and afterwards between the drums E, E^1, and rollers e, in the direction indicated by the arrows to rollers e^1, e^1, where it is delivered to the cylinders F, F^1, which cut it up into sheets. The cylinder F is provided with a saw blade, placed between two metal bars fixed on springs, these bars being made to slightly project from the cylinder. The cylinder F^1 is also provided with two bars, which in this case are fixed, but also projecting from the cylinder and exactly corresponding with those of cylinder F. When the two bars of cylinder F meet the bars of F^1, they become compressed, the saw blade is

disengaged and enters the space between the bars of cylinder F^1, thus severing the paper. The cylinders F, F^1, make the same number of revolutions as the cylinders H, H^1, consequently a sheet will be cut off for every revolution of cylinders H, H^1. The drums E, E^1, unwind from the rolls at each revolution a length of paper equal to their circumference, and on setting the machine in motion the paper is conducted by means of tapes over rollers d^1, d^1, drums E, E^1, e, e, e^1, e^1, between the cutter cylinders F, F^1.

From the foregoing it will be seen that as the length of the sheet is dependent on the size of the drums E, E^1, it may be readily changed by varying the diameter of these drums or changing the gearing so as to vary the surface speed.

In the arrangement shown the paper is unwound by draught simply, but this is best effected by mounting the roll of paper on a cylinder, performing the same number of revolutions as the impression cylinders, and unwinding at each turn a length of paper equal to its circumference. The length of the sheet would in this case also vary according to the diameter of the cylinder, by contact with which the roll of paper is unwound.

The paper after being cut into sheets at F, F^1, is conveyed by the tapes over rollers g, g^1, and the small rollers x, x^1, to the blanket or impression cylinders J, J^1, and the sheets are thence all conducted between the rollers m, m. The sheets in passing over cylinder J are printed on one side by the plates of cylinder H, and passing thence to cylinder J^1 are reversed, that is to say, the side which has been printed by cylinder H is applied on cylinder J^1, and the blank side receives an impression from cylinder H^1, which is also provided with plates. The sheets after being printed on both sides are passed between the two rollers m, m, whence they are conveyed in succession to the four flyers or mechanical receivers.

The paper after being cut up into sheets is conducted direct to the printing cylinders by means of the small rollers x, x^1. By this arrangement the cylinders J^1, J^1, are rendered easy of access.

The inking apparatus is composed of the ink fountains L, L^1; X, X^1, ductor rollers rotating in the ink troughs; Y, Y^1, vibrating rollers which are alternately in contact with rollers X, X^1, and inking tables K, K^1, the latter having continuous rotary motion. The ink is thus deposited on the inking tables K, K^1, by the aid of ductor rollers X, X^1. The rollers Z, Z^1, turn in contact with tables K, K^1, and have also a sideway motion for distributing the ink; V, V^1, inking rollers rotating in contact both with the tables K, K^1, and the plates on the cylinders H, H^1, which rotate in the contrary direction to K, K^1. The inking rollers V, V, V^1, V^1, receive a continual supply of ink from the inking tables K, K^1, for inking the plates.

In order to deliver the sheets to the four flyers, or mechanical receivers, below the rollers m, m, is placed the first sheet-divider M, consisting of two longitudinal sliding frames carrying four rollers n, n, i, i. These slides have a movement imparted by an eccentric N, in such manner that the rollers n and i are alternately brought under the rollers m, m.

In the position shown in Fig. 6397, the rollers n, n, correspond with the two rollers m, m, and the printed sheet will pass between the tapes on n, n, and be conveyed between the two rollers which are on the left-hand divider O. When, on the contrary, eccentric N brings the two rollers i, i, under rollers m, m, the sheet will pass between the tapes on i, i, and be conducted to the right-hand divider O^1. Thus, by the aid of divider M, the sheets are alternately conducted to either end of the machine. The side divider O is composed of two vertically moving bars carrying two rollers over which the tapes from n, n, pass. The vertical bars are operated by eccentrics P, which give an up and down motion to them. The two rollers carried on the bars of the divider O are then opposite the two rollers u, u, consequently the sheet will pass between the latter in the direction indicated by the arrows to the arm or flyer Q, by which they are laid on table R. In the lower position of the sliding frames the two rollers carried by them are brought opposite the rollers r, r, and the sheets passing through n, n, are conducted between r, r, following the direction indicated by the arrows until they arrive at the flyer Q^2, by which they are laid on the table R^1. A similar distribution of the sheets is performed by the divider O^1, which conducts the sheets alternately to flyers Q^1 and Q″.

It will thus be seen that each flyer, Q, Q^1, receives only one fourth of the printed sheets.

With dividers arranged in the above manner there may be any number of flyers placed on the machine, as desired.

The sheets on reaching the delivering rollers S, S^2, S^1, S^{12}, are cut in the longitudinal direction of the machine by the knives T, T^1, formed of steel discs working against steel rings fixed on rollers S^2, S^{12}. These circular knives may be thrown out of gear to allow the sheet to pass through without being cut, if desired.

A great advantage with this machine is that it may be converted into a hand feeder by providing it with feeding boards from which the sheets are fed by hand to the cylinders F, E. The cylinders F, F^1, in this case simply serve as entering drums.

The general arrangement of the Walter press is shown by the diagram, Fig. 6398.

The reel of paper is at the extreme right. The paper is led from the reel into a series of small cylinders, where it is damped, and is then brought between the first and second of four cylinders raised perpendicularly above each other. The top cylinder is encircled by stereotype casts from four pages of type, and the lowest of the four cylinders is similarly surrounded by stereotype plates of the remaining four pages of the newspaper. The paper, in passing between the first and second cylinders, receives the impression on one side. It then passes backwards between the second and third cylinders, and resumes its forward direction in passing between the third and fourth cylinders, from the latter of which it receives an impression from the stereotype plates on the side of the paper exactly opposite the part printed by the top cylinder. The paper continues its course onwards till it passes between two cylinders exactly in the centre of the machine, where it is cut into sheets, each forming a complete newspaper. Adjoining the cutting cylinders is an index, which counts each sheet as it is cut. After the cutting is accomplished, the sheet is led forward by a set of tapes till it reaches the apex of the triangle formed by the left portion of the machine. From this point it

descends perpendicularly, and the sheets are thrown alternately forwards and backwards on to the boards. The series of rollers shown immediately to the left of the reel, and a similar series on the

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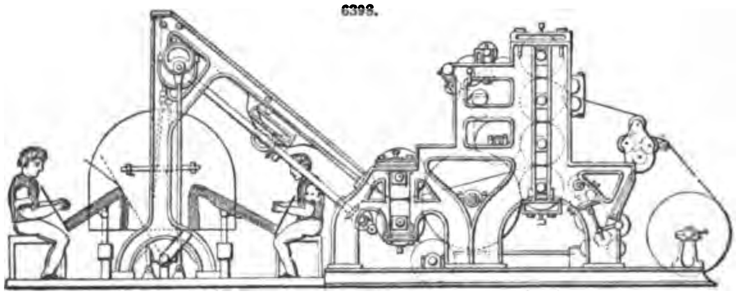


left of the upper printing cylinder, supply and distribute the ink, which is pumped up by mechanical contrivances from a cistern placed beneath the floor.

PUDDLING. FR., *Puddlage;* GER., *Puddeln.*

See IRON.

PULLEY. FR., *Poulie;* GER., *Rollkloben;* ITAL., *Puleggia;* SPAN., *Polea.*

See MECHANICAL MOVEMENTS.

PUMP. FR., *Pompe;* GER., *Pumpe;* ITAL., *Tromba;* SPAN., *Bomba.*

In our articles on Drainage and Hydraulic Machines we had occasion incidentally to investigate the nature of a pump, and to describe several novel and important specimens actually in use. But as those articles are devoted, in the one case, to a particular purpose to which a pump may be applied, and, in the other case, to the far wider subject of hydraulic machinery in general, those investigations and descriptions were necessarily wanting in comprehensiveness and in that natural sequence of ideas requisite to a full and precise understanding of a matter more than usually complex. We shall therefore review some ground already hastily passed over, and where occasion requires, re-investigate principles previously enunciated and briefly discussed.

A pump is a machine for applying force to a fluid, either for the purpose of causing it to ascend from a lower to a higher level, or of making it flow against an opposing force other than that of gravity acting upon the portion of the fluid to be put in motion. This definition divides pumps into two great primary classes, which may be subdivided into several secondary classes, according to the special use to which the pumps are applied. Thus arranged, the subject appears as follows;—First division, pumps for draining mines, pumps for surface draining, pumps for irrigation, pumps for water-supply, pumps for raising particular liquids, contractors' pumps, pumps for emptying docks, bilge-pumps; second division, pumps for supplying hydraulic machinery, feed-pumps, air-pumps. We purpose to consider the subject of pumping machinery under these several heads, omitting the purely elementary portion, which has already been given in the article on Drainage. Before, however, we can intelligibly point out the distinctive features of the many kinds and varieties of pumps now in use, and intelligently determine their respective merits, it will be necessary to consider the requirements which any pump must satisfy to render it a perfect machine.

The first of these conditions or requirements is due efficiency. This condition is common to all classes of machines and is of primary importance in all. Until very recently, pumps have been, from this point of view, the most unsatisfactory of mechanical appliances. It has been stated on good authority that previous to the International Exhibition of 1851, no pump ever attained an efficiency of 40 per cent., and that many returned no more than 10 per cent. of the force expended in water raised. Since that time, however, the attention of engineers has been directed to the subject, and such improvements of design and construction have been effected that this enormous loss of power has been reduced, in average cases, by at least one-half. So far this is a very satisfactory result. But there yet remains much to be done before that degree of perfection is reached to which other kinds of machinery have been carried. The large proportion of the motive power absorbed by the organs of transmission, and the loss of water through the valves, still leave much to be desired. In determining what is due efficiency, regard must be had to the character of the work, and also to the conditions under which it is performed. A pump for draining a mine, for instance, may return in water raised 10 per cent. less than another pump applied to the draining of a surface, and yet the former may be a more satisfactory machine than the latter. Thus, due efficiency must be considered *relatively*, not *absolutely*. This is more or less true of all machines; but it is especially true of pumps, which are established under such a variety of circumstances.

A second requirement for a pump is that it shall be simple in construction, and not liable to get out of order. The nature of the work required of a pump demands almost absolute immunity from derangement. It is erected in positions where it is most difficult of access, and the cost of repairs is consequently excessive. Moreover, if required to work continuously, or at short intervals, a delay of a few hours may result in incalculable loss and inconvenience. And it must not be forgotten that pumps, more perhaps than any other kind of machinery, are entrusted to the management of unskilled hands. The rough and ignorant usage to which pumps of all kinds are constantly subjected, would be speedily fatal to their working, were they not constructed of few moving parts, of great strength and simplicity, easily replaced in case of accident, and capable of being repaired by the most inexperienced hands.

The above conditions must be satisfied by every kind of pump whatsoever; we shall mention hereafter those which are essential to particular varieties.

Force may be applied to a liquid through the medium of a pump in two ways. One way is to bring the liquid upon a piston working up and down in a cylinder, to the upper end of which a pipe may be fixed; the upward motion of the piston then raises the water at every successive stroke until it reaches the top of the cylinder or pipe. Pumps of this kind are called *lift*-pumps, because the liquid is lifted by the piston to the required height. And it is obvious that this height is limited only by the strength of the materials and the force available. The way in which the liquid is brought upon the piston is shown in the article on Drainage, Fig. 2527. It will be seen by this figure that atmospheric pressure is employed to raise the water a portion of the height. This part of the pump is called the suction, and that above the piston the lift. The suction should not exceed 25 ft. in height, for though a column of water is not in equilibrium with the atmospheric pressure until it reaches a height of about 33 ft., the resistance occasioned by friction, as well as the rapid flow necessary to the satisfactory working of a pump, forbids the attaining of this limit. Even 25 ft. is too high to ensure a perfect working, and when large quantities of water have to be raised, it is better to limit the suction to 20 ft. The height of the lift is theoretically limited only by the considerations mentioned above, but practically the limit is somewhat restricted. As shown in the figure already referred to, the piston-rod is inside the ascension-pipe, and consequently lessens the area or water space on that side of the piston, thereby largely increasing the friction. This circumstance necessitates the use of iron for the piston-rods, in order to reduce their dimensions to a minimum. But even with this material, the dimensions requisite for a great height would considerably reduce the efficiency of the pump. Another reason for limiting the height of a lift is the necessity of counterbalancing the whole weight of the piston and rods. But a more serious objection to the use of a lift-pump for a great height is the rapid wear and frequent derangement to which it is liable, with the consequent difficulty of repairs. This defect constitutes an objection to the use of lift-pumps at all, where a continuous working is an essential condition. For this reason they are unsuitable for the work of a town water-supply, though they are frequently recommended for that use, and as frequently employed. The wear of the leather rings forming the packing of the bucket of a lift-pump is often extremely rapid, particularly when it is aided by the action of water charged with particles of sand or gravel, or contaminated by mineral solutions that impart a corrosive quality. And there is no certainty as to the time a bucket will last; for it may vary, according to circumstances, from two or three days to two or three months. The labour of changing is in all cases expensive, but it becomes extremely so for a great height. Hence, it must be concluded that lift-pumps are unsuitable for great heights and continuous working, and that consequently they are not to be recommended in cases where either of these conditions exists.

The other mode of applying force to a fluid by means of a pump is to bring the fluid beneath a piston working up and down inside a cylinder; the downward stroke of the piston then forces the fluid up through a pipe provided for the purpose, or in any other direction that may be required. This kind of pump, the details of which are given under the head of Drainage, Figs. 2529, 2530, possesses many advantages over the other. The plunger variety, which is by far the best, was invented by Sir Samuel Morland in 1675. A remarkable feature of this invention is the stuffing box, without which the steam-engine could hardly have come into existence. The hemp packing of this stuffing box is greatly preferable to the leathers of a piston, as giving less friction, being much cheaper, more durable, more secure, and, what is of immense importance in all cases, more easily seen and repaired when defective. The packing may be tightened without even stopping the engine, and it requires only a few minutes' interruption of work to replace it when worn out. In no case is it necessary to remove the plunger itself, while, with the lifting pump, the bucket must always be withdrawn entirely from the working barrel, thus causing considerable delay every time the leathering requires to be repaired or renewed. Another advantage of the plunger-pump, in the case of rods being employed, is that it requires less counterweight to be used. The height to which a liquid may be raised by a force-pump is theoretically limited only by the strength of the materials and the force available, as in the case of the lifting pump; but, unlike the latter, it is not restricted by other practical considerations. The force-pump thus possesses great advantages over the lift in most cases where a pump can be applied, but it is especially suitable in those where either of the conditions of a considerable height or a continuous working exists.

In the two kinds of pumps described above, the pistons have a reciprocating motion. But there are other kinds, partaking of the nature of both the lift and the force pump, which have either a revolving piston or a set of revolving blades that act upon the liquid in the same way as a fan acts upon air. The former are called *rotary*, the latter *centrifugal* pumps. Yet another kind of water-raising machine exists, known as the chain-pump, which might with more propriety be called a water-elevator, since it differs in no essential feature from a grain-elevator, and lacks every characteristic of a pump. We shall consider these several varieties under their proper heads.

Reciprocating Pumps.—The essential parts of a reciprocating pump are,—the cylinder or barrel, the valves, the piston, and the piston-rod; and on the design and construction of these the efficiency of the pump chiefly depends. In order to acquire a full understanding of the nature of these constituent parts, it will be necessary to investigate briefly the principles and the conditions to which their action is subject.

The Cylinder.—As the piston or bucket reciprocates in constant contact with the walls of the cylinder, the latter must be bored true in order that the piston may fit accurately and work with as little friction as possible. The tendency of the cylinder to become oxidized when iron is used as the material of construction often constitutes a serious difficulty, especially in cases where the water or other liquid to be raised is charged with substances capable of determining rapid oxidation. In pumps for draining mines, the cylinders and pistons, when of iron, are frequently destroyed in a short time, and, of course, in such circumstances a satisfactory degree of efficiency is not to be looked for. To remedy this defect, it is usual to line the cylinders with brass, and though the first cost is considerably enhanced thereby, the additional outlay is soon recovered in

the higher efficiency of the pump, while the greater durability of the cylinder renders such outlay a real source of economy. The diameter of the cylinder is generally greater than that of the suction or the discharge pipes, and is calculated in inches by the following formula; $D = \sqrt{\frac{G}{\cdot 034\,L\,N}}$, in which G represents the quantity in gallons to be delivered a minute, L the length of the stroke in feet, and N the number of single strokes a minute. To find the quantity in gallons that a given pump is capable of delivering a minute, $G = \cdot 034\,D^2\,L\,N$; and to find the quantity in gallons delivered at each stroke, $G = D^2\,S \times \cdot 00283$.

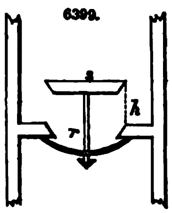
The Valves.—The valves are a very important part of reciprocating pumps, and deserve the most careful attention. A large percentage of the power lost in a pump, perhaps the largest percentage of that power, is due to the influence of the valves. Yet, while numberless improvements have been and are being almost daily effected in other parts which absorb power, few attempts have been made to reduce the loss of efficiency in this direction. The cause of this neglect seems to lie in the fact that the loss is supposed due to the form of the valve, and as several modified forms of which much was expected by their inventors, failed to bring about any appreciable result, the exertions of mechanical men have been diverted into other and more promising directions. That this supposition is an erroneous one we hope to show in the following remarks, and at the same time to point out what, in our opinion, should be the degree of perfection aimed at in the design and construction of a valve that is to be actuated by a liquid.

In the first place, it must be borne in mind that a valve has to fulfil two requirements of an opposite nature, and that therefore the fulfilment of one is incompatible with the fulfilment of the other. These requirements are to afford an unobstructed passage to the water in one direction, and to close the passage entirely in the contrary direction. The complete fulfilment of these requirements implies the satisfaction of antagonistic conditions. Those imposed by the former are, that the valve shall be of the same weight as the water it displaces, so that it may offer no resistance to the ascending column, that its presence shall not contract the area of the passage below that of the water-way covered by the valve when closed, or otherwise obstruct the flow of the water, that it shall move with the same velocity as the water. But even this set of conditions, apart from those implied in the second requirement, cannot be wholly complied with. Every variety of valve applicable to a pump belongs to one of two classes, known respectively as the *hinged* and the *spindle* valve. The former is hinged to its seat like a trap-door, and is so well known as to need no description; this kind is usually called the clack-valve. The latter rises perpendicularly from its seat, and the extent of its motion is limited by a spindle or rod fixed to its lower face, or by some similar arrangement. Now, it is evident that both these kinds may be made of any degree of lightness, and that therefore they fulfil equally the first condition. But the second condition can be satisfied only by the hinged valve; for this kind may open back out of the way of the passing current, while the spindle-valve, rising perpendicularly—that is, keeping its axis always coincident with the axis of the water-way—must necessarily obstruct the passage. The third condition is fulfilled only by the spindle-valve for if this kind be equal in weight to the water it displaces, it will offer no resistance to the latter, and will consequently move with the same velocity, but the hinged valve being constrained to move in a circle, the velocity of any point in the valve varies as its distance from the centre. The consequences of this motion are, that the entering current is forced away from the side of the hinge, and a whirling motion is communicated to the water above the valve. The loss of efficiency due to this cause is probably considerable, fully equal certainly to that occasioned by the diversion of the current resulting from the obstruction offered by the spindle-valve. Thus it will be seen that the first requirement, even when considered apart from the second, cannot be completely fulfilled. But when the second requirement is introduced into the question, an important modification of the former conditions ensues. For the latter demands that the tendency of the water to return shall close the valve, or at least be capable of closing it, that the valve shall be sufficiently strong to support the weight of the superincumbent water, and that it shall not allow any water to escape during the act of closing. The first of these conditions does not permit the clack to fulfil the second condition imposed by the first requirement by opening back out of the way of the passing current, for it is obvious that if this valve be open at an angle of 90°, a return current will not close it. The utmost limit that can be allowed is 70°. Hence the entering water will be thrown off the face of the valve at an angle of 20°, and against the wall of the cylinder at the same angle with the forward line of direction. The resistance occasioned by these circumstances may be taken as at least equal to that caused by a knee of 20°. The second and third of the above conditions require the valve to be heavier than the liquid, since the requisite strength can hardly be obtained without the employment of metal, and the valve must be capable of closing by its own weight. The excess of this weight above that of the liquid has of course to be supported by the entering current during the whole time of admission. Hence another source of resistance, due to the impossibility of fulfilling the first condition implied in the first requirement. The last of the above conditions is of the highest importance, and demands the greatest elucidation, since it refers to the chief source of loss, exerts the greatest mod..ying influence upon the first set of conditions, and seems to be the one least understood. The quantity of water lost through the valves, which quantity is usually termed the slip of the valve, is rarely equal in any two pumps of the same dimensions, and it varies from 4 to 20 per cent. of the stroke; the former percentage, however, is of very rare occurrence, though the latter is common. We believe that this serious loss, as well as the wide limits within which it is found to vary, arises from failing to appreciate the true nature of the slip. The fact that the loss is not reduced to some definite limits is a proof that nothing definite is known concerning the matter. The ignorance of makers is, in this case, excusable, since scientific writers, whose duty it is to be pioneers to the practical man, are silent on the subject, or at best utter but an uncertain sound. Thus we find it stated by one authority that the loss by slip is due rather to defects in construction than to faults in design, while another attributes it mainly to the

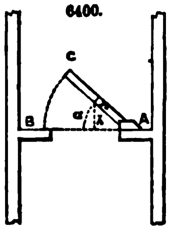
form of the valve. Neither of these views is, however, borne out by experience. Yet the question cannot be of a nature to defy investigation, nor can it be impossible to find a solution of a practical character. Indeed, it must be a simple and an easy matter to obtain approximate results sufficiently accurate to constitute a reliable and ready guide to practice. Such results we shall endeavour to obtain, leaving to mere theorists the labour of determining with rigid exactitude all the elements of the question. It may be well to state, however, that the conclusions to which our arguments lead have been fully confirmed by experiment.

It is manifest that if the piston pause at the top of its stroke, the column of water which then fills the cylinder will remain at rest; and if the pause be sufficiently long, the valves will close by their own weight. In this case the water displaced by the falling valve rises above the latter, and consequently none escapes through the valve aperture. The slip is therefore reduced to zero. But if, on the contrary, no such pause be made, the valve will be closed by hydraulic pressure, that is, by the force of the returning current, provided the velocity of the piston be not inferior to that of the valve, which is due to its own weight. And it must be remembered that this velocity in a submerged valve is not great. Now it is evident, in this case, that the water occupying the space passed through by the valve in closing must be expelled, since it cannot, as in the former case, rise above the valve as the latter descends. This case, therefore, represents the maximum slip, and it is this that we have to determine. Let us first take the case of the spindle-valve, Fig. 6399. This valve rises from its seating to a height h limited by its spindle or rod r. If the piston return instantly with a velocity equal to that of the falling valve, we shall have a case of the maximum slip. By equal velocities, it must be understood that we mean relatively equal velocities; for if the area of the plunger be twice that of the valve, it is obvious that to possess a relatively equal velocity the former must descend with only half the absolute velocity of the latter, since they then displace equal volumes in equal times. It is manifest that in this case the quantity of water expelled by the forcing down of the valve is the column having the upper face of the valve as its base, and as its height the distance h of this face from the seating. The amount of slip may therefore be expressed by $s \times h$, s being the area of the valve face. The same reasoning applies to the hinged valve, Fig. 6400, the only difference being that the height of the column is, in this case, the length of the arc a, or the path of the centre of the valve.

6399.



6400.



It follows from the foregoing that when no pause is made at the end of the stroke, the amount of slip increases as the lift of the valve. This conclusion is slightly modified in the case of the hinged valve by the speed of the piston, as we shall see later; but, generally, it may be said that the slip = the valve area × the mean lift. Here we see at once the cause of the serious loss of water that constantly takes place in pumps, as well as the absence of uniformity in the amount of the loss. Valves are made to open as widely as possible, in order to afford an unobstructed passage to the water. To render this proceeding justifiable, the loss of efficiency occasioned by the obstruction offered by the valve must be greater than that due to the slip. And it must be remembered that the water which flows back through the valves represents so much power lost, the same water having been previously lifted. Let us examine this question approximately by taking the angle made by the hinged valve with the forward line of direction as equivalent to a knee of the same angle; for we have already shown that the spindle valve obstructs equally at all heights, and consequently all increase of lift beyond a certain height, which we shall presently determine, is obviously pure loss. It may be well to state here that the foregoing remarks apply equally to the forcing and the suction valves, as the column of water above the former, not being supported by the pressure of the atmosphere, acts in the same way as the plunger acts upon the latter. We have seen that the hinged valve, when opened to its utmost limit, forms a knee of 20°. Suppose now a valve 4 in. in diameter open to this angle of 70°. The resistance offered by the knee, expressed as head of water in feet necessary to overcome it, is $H = 0155\, V^2 K$, V being the velocity in feet a second, and K a suitable coefficient. This coefficient is ·046 for an angle of 20°, and ·36 for an angle of 60°. Taking $V = 4$, we have $H = \cdot 0114$ ft. $= \cdot 137$ in., and $12 \cdot 56 \times 137 = 1 \cdot 62$ cub. in. The slip $S = 1 \cdot 22 \times 2 \times 12 \cdot 56 = 30 \cdot 65$ cub. in., total, $1 \cdot 62 + 30 \cdot 65 = 32 \cdot 27$ cub. in. If, now, we suppose this same valve open at an angle of 30° only, we shall have a knee of 60°, and the resistances, calculated as before, are $H = 09$ ft. $= 1 \cdot 08$ in., and $12 \cdot 56 \times 1 \cdot 08 = 13\ 56$ cub. in., and $S = \cdot 52 \times 2 \times 12\ 56 = 13 \cdot 06$ cub. in.; total, $13 \cdot 56 + 13 \cdot 06 = 26\ 62$ cub. in. Thus, by adopting the former angle of opening, we diminish the relative efficiency of the pump by an amount represented by 5 64 cub. in. of water, and the power of the pump by 17·59 cub. in. a stroke—the latter a serious loss. And the greater travel of the valve causes a greater disturbance in the water, whereby the efficiency is again diminished, and a more violent concussion, resulting in a speedy destruction of the valve. Hence the practice of giving a high lift to the valve for the purpose of affording an unobstructed passage to the water is unjustifiable.

It now becomes necessary to determine what is the most advantageous degree of lift to be given to a pump-valve. The foregoing arguments show that the gain increases as the lift is diminished. What is the limit in this direction? Evidently, if the valve be only slightly raised, the area of the passage afforded for the water between the lower edge of the valve and its seat will be less than that of its lower face, or the aperture which this face covers. Suppose, for example, a spindle-valve 4 in. in diameter; the area of the water-way closed by this valve is 12·56 sq. in. If the lift of the valve be limited to ¼ in., the passage afforded to the water will be $4 \times 3 \cdot 1416 \times \cdot 25 = 3 \cdot 141$ sq. in., or a diameter of 2 in. When the water reaches this passage, the vein will be contracted, and will reduce the size of the opening still more. Through the opening thus reduced the water must pass without any diminution of volume in a given time; hence its velocity must be increased. The

excess of force necessary to produce this excess of velocity, the direction of the motion remaining the same, will evidently be the effect of the contraction, and will represent the resistance which the contraction occasions. To find the mathematical expression of this resistance, put $D =$ the diameter of the water-way, $D' =$ the diameter of the contracted passage, and $f =$ the coefficient of contraction corresponding thereto. The expression of the velocity will then be $V \frac{D^2}{f D'^2}$; the force requisite to produce this velocity, or the head of water in feet, will consequently be $\cdot 0155 \, V^2 \frac{D^4}{f^2 D'^4}$, the head due to the velocity of the water before reaching the contracted passage being $\cdot 0155 \, V^2$; the excess of head, or the resistance due to the contraction, will thus be

$$\cdot 0155 \, V^2 \left(\frac{D^4}{f^2 D'^4} - 1\right) = \cdot 0155 \, V^2 D^4 \left(\frac{1}{f^2 D'^4} - \frac{1}{D^4}\right).$$

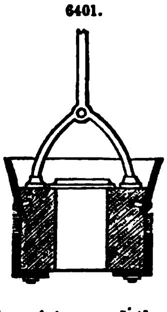
Hence it follows that if a valve be not opened sufficiently to afford an uncontracted passage to the water, the resistances will be so increased as to outweigh the advantages resulting from the lowness of the lift; and the limit may be fixed at that point where contraction begins. The best degree of lift for pump-valves—in other words, the compromise between conflicting conditions that reduces the sum of their several disadvantages to a minimum—is thus expressed for both kinds of valves with sufficient accuracy for practical purposes by the simple formula, $L = \cdot 25 \, D$, D being the diameter of the valve aperture, and L the height of that point in the valve which, when the latter rests upon its seat, coincides with the axis of that aperture.

The kind of valve most frequently used, especially in large pumps, is the clack. There are numerous modifications of this as well as the spindle variety, but as we intend to devote an article to the subject of valves generally, we shall not describe them here.

When the water possesses corrosive qualities, metal valves are unsuitable, and as the water of mines is usually of this character, wood and leather are almost exclusively used in mine pumps. Whenever metal valves are so employed, they are made to beat or fall, not upon seats of iron, brass, or other hard metal, but upon faced rings of hard wood let into the part which would otherwise form the seat of the valve. By this means the violent concussion to which they are subjected in closing at the return stroke of the plunger is lessened. Sometimes a soft metallic alloy of lead or tin is used instead of the facing of wood.

The Piston.—The efficiency of a pump depends in a great manner upon the state of the piston. If the latter is badly made or imperfectly leathered or packed, or if it has got out of order in consequence of wear and corrosion—and it is the part most subject to these influences—a large proportion of the motive force is absorbed by useless friction, or the pump partially fails to act by reason of the parts not being air-tight. We have already stated that the bucket, or lift-pump piston, is much more liable to derangement and wear than the plunger or forcing-pump piston. This is due to the different manner of packing them rather than to their different forms. The common form of lift-pump piston is shown in Fig. 6401. It consists of a hollow cylindrical piece of wood, usually elm boiled in oil, to which an iron stirrup is attached, and having a valve on its upper end. In small pumps iron or brass is used instead of elm wood. The advantage of employing metal for this purpose is that a less thickness being sufficient, a larger water-way may be obtained. To make the piston work air-tight in the cylinder, a piece of stout leather is applied to the outer surface in the manner shown in the figure, and held by a band or hoop. Around the lower end is a second hoop, and the hollow between these is filled up by winding on skeins of hemp dipped in melted tallow. As the hemp projects slightly beyond the hoops, it presses against the walls of the cylinder; and a sufficient quantity must be wound on to make the pressure great enough to prevent the passage of air, and no more than enough, as any excess of friction is a waste of power and a cause of unnecessary wear. The weight of the water above the piston presses the leather outwards against the walls of the cylinder, and so prevents a leakage between the latter and the piston. Numerous modifications of these arrangements may be and are made, but they do not differ essentially from the system we have described. Some of these modifications have for their object the enlarging of the water-way through the piston, and that this object is a desirable one will be acknowledged when it is borne in mind that considerable loss of power is occasioned by forcing a column of water through a contracted passage.

6401.



The plunger or solid piston of the forcing pump works through a stuffing box, and is therefore not subject to the wear and the liability to derangement which renders the bucket-piston objectionable. It should be accurately turned, so that there may be no unnecessary friction or wear of the packing. When of small dimensions the plunger may be wholly of brass, but when large it should be encased in brass, as iron is quite unsuitable in consequence of its liability to corrosion.

The weight upon the piston of a pump is always equal to that of a column of water whose base is the area of the piston, and whose height is the vertical distance from the surface of the pool to the point of discharge. Let H be this height in feet, and D the diameter of the piston, also in feet, and let us take the piston at any part of its stroke. Denoting the vertical distance from this point in the stroke to the point of discharge by h, and the height of this same point above the surface of the pool by h^1, we have $h + h^1 = H$. The piston will be pressed down by the weight of the atmosphere and by that of the column of water above it. Representing the height of the column of water requisite to hold the atmospheric pressure in equilibrium by t, and the ratio $\frac{3 \cdot 1416}{4}$ by π^1, the expression of this weight is $62 \cdot 4 \, \pi^1 D^2 (t + h)$. The counter-pressure, or pressure beneath the

piston, is equal to the atmospheric column, less the column of water below the piston; that is, to $62 \cdot 4\ \pi^1\ D^2\ (t - h^1)$. The resultant of these two pressures, or the effective load upon the piston, is therefore $62 \cdot 4\ \pi^1\ D^2 (t + h) - 62 \cdot 4\ \pi^1\ D^2\ (t - h^1) = 62 \cdot 4\ \pi^1\ D^2\ (h + h^1) = 62 \cdot 4\ \pi^1\ D^2\ H$, which it was required to prove. This pressure upon the piston is independent of the diameter and inclination of the pipes, and is evidently the same for the forcing as for the lift pump.

The stroke of a pump-piston should be made as long as practical considerations will admit. The quantity of water lost through the valves is the same for a long as for a short stroke, the diameter being the same. Hence the long possesses a considerable advantage over the short stroke in this respect. But a more important advantage consists in the less frequent change of direction. When it is considered that in large pumps the inertia of an enormous mass has to be overcome at every change of stroke, the reality of this advantage will be readily conceded. In mine pumps, the rods of which often exceed 100 tons in weight, the stroke is usually from 8 to 10 ft.

Experiments have shown that when the valves are of the clack variety, the slip, in some cases, decreases with the increase of speed in the piston. In some cases by doubling the velocity the amount of slip has been reduced by one-half. This is due to the fact that the valve is closed by hydraulic pressure. When the valve is heavy and the velocity of the water low, a small quantity escapes before the inertia of the valve and the friction of its hinge has been overcome by the returning stream and its own gravity. But when the piston moves with a high velocity, the whole pressure of the piston is directly and instantaneously communicated to the valve, which is then closed wholly, as we have already seen, by hydraulic pressure. If this explanation is the true one, the slip will decrease with the increase of velocity only within certain limits, and no experiments of which we are cognizant have proved the contrary.

The speed of the piston is limited by the velocity of flow in the suction-pipe. To find the extreme speed at which a piston may be driven, it will therefore be necessary to determine this velocity. Suppose the piston suddenly raised the whole length of its stroke, leaving a perfect vacuum below it, the time T requisite to bring the water to the top of this space, provided it be already up to the sleeping valve, is

$$T = \frac{2\ \pi^1\ D^2}{m\ s\ \sqrt{2\,g}} \left(\sqrt{t - L} - \sqrt{t - L - l}\right),$$

L being the height of the valve above the surface of the pool, l the length of the stroke, s the area of the valve aperture, and m a suitable coefficient of contraction, the other letters having the same signification as before. This formula does not take into account the friction of the water in the suction-pipe; but in this case it would be very little. Representing the mean velocity with which the water ascends in the cylinder by v, we have $v = \frac{l}{T}$. If the piston possessed a velocity V greater than v, the water would be unable to follow it. V must therefore be less than $\frac{l}{T}$; and it should not be greater than two-thirds of $\frac{l}{T}$. In practice t may be taken as equal to 32 ft., and m to include the friction of the water in the pipe, as equal to $0 \cdot 60$.

The expressions for v and T show that the velocity with which the water ascends in the cylinder, and consequently that which may be given to the piston, decreases as the length of the suction-pipe increases, and increases with its diameter. In large pumps the extreme limit is never attained on account of the great weight of the moving parts and the consequent strain which a high velocity would produce. Usually the speed of the piston in such cases varies from 6 in. to 15 in. a second.

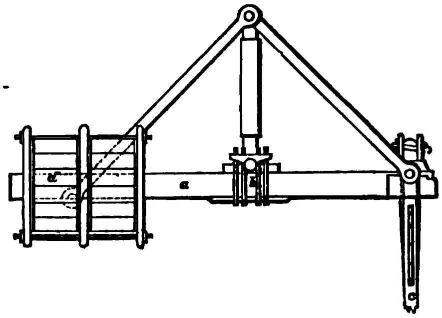
Piston-rods.—When the pump and the motor are situate upon the same bed or near to each other, the piston is easily and efficiently worked through the medium of ordinary connecting rods. In such cases the pump-piston is connected with the steam-piston, when steam is the motor, either directly, by means of a rod common to both, or indirectly, by means of a crank. With a water-wheel the latter is the only method available. When, however, the pump is situate at a great distance from the motor, the transmission of the motive force to the piston is one of the most difficult problems relating to the subject of pumping. Numerous attempts have been made to solve this problem satisfactorily; but the success which has attended the efforts of inventors has, until recently at least, not been commensurate with the ingenuity displayed.

The most obvious means of transmitting the force in these cases, as in those where the motor and the pump are near together, is, of course, the connecting rod adequately extended; and this means has, for want of a better, been generally adopted; for it will be seen that, though a connecting rod is a very suitable medium so long as it is of small dimensions, it becomes most unsuitable when the dimensions assume excessive proportions. When, for example, the pump is at the bottom of a mine and the motor at surface, the weight of the intermediate rods often greatly exceeds that of the column of water to be raised, and consequently a large proportion of the motive force is absorbed by the friction of these rods and in overcoming the inertia of their enormous mass. This defect, as well as others of considerable importance, will be made more apparent by a description of the system at present in use.

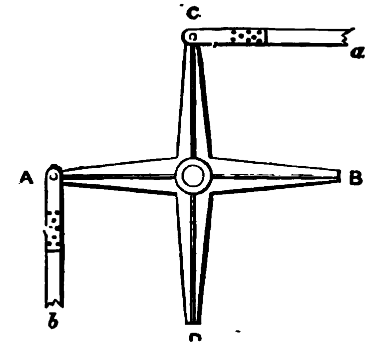
The operations in a mine are carried on at several different levels. In metalliferous mines, in which the ore is found in lodes, these levels are usually at a depth of ten fathoms below each other; but in coal mines, in which the mineral exists in seams, the levels are in those seams. The water which collects in these several levels or stages is conveyed to a tank fixed in a recess cut in the side of the shaft. At the bottom level it flows into a pool or well called the sump. A lift-pump is fixed from the sump to the tank on the next level, and force-pumps are placed from tank to tank. Thus the water is raised by stages. To actuate the plungers of the force-pumps and the piston of

the lift, a rod is carried down the shaft. As the depth of the shaft in a mine that has been worked for any length of time is seldom less than 1000 ft., and as the quantity to be raised is frequently great, it is obvious that this rod must be very strong, and therefore must possess large dimensions. Usually it is composed of balks of Memel timber, perfectly sound and straight, and without knots or faults of any kind, such as are used for the masts of ships, and of as great a length as can be obtained. The lengths are put together by scarfed joints, and secured by stout wrought-iron plates bolted through the timber. To this main rod the pistons of the pumps at the several levels are firmly attached by means of a set-off and strong iron straps. These piston-rods work through guides to keep them in a straight line, and for the same purpose similar guides are placed at intervals down the shaft against the main rod. The rod where it passed through the guides is cased with hard wood, and kept well greased to lessen the friction. It will be seen from this description that the rods are of enormous weight. In deep mines, the main rod alone frequently weighs upwards of 70 tons. The mode of working the pumps is to make the motor raise the rods, and then to leave the weight of the latter to force up the water. As, however, the weight of the rods is usually greatly in excess of that required to raise the water, this excess is taken off by means of a loaded lever, called a balance-lever, or more commonly a balance-bob. Fig. 6402 shows one of these balance-bobs. It consists of a stout balk of timber *a*, often from 20 to 30 ft. in length, turning about an axis at *b*, and loaded at the end *d* by a box filled with stones or other heavy materials.

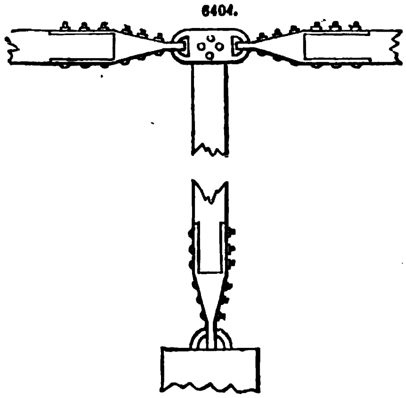
6402.



6403.



6404.



The two ends are supported by iron ties passing over an upright support upon the axis One of these bobs is placed at surface and others at intervals down the shaft, the unloaded end being fixed to the main rod *c*. When the shaft is inclined, which is frequently the case, the main rod is made to rest upon friction rollers; in other respects the arrangements are unchanged by this circumstance. A vertical rod is made to communicate motion to an inclined rod, or *vice versâ*, by means of a bent lever, called a V or angle bob. As the motor is often situate at a considerable distance from the shaft, especially when the pumps in two shafts are worked by the same motor, the rods are carried along the surface of the ground, and connected with the main rod in the shaft by one of these V-bobs. Fig. 6403 shows this arrangement. The horizontal, or, as they are usually termed, flat rods *a*, are attached by means of iron straps to the arm C of the lever, and the main rod in the shaft *b* is attached in the same way to the other arm A. When in this position, the V-bob is frequently double, as in the figure, the arms D and B serving as counterweights to A and C. Flat rods are carried upon friction rollers where the surface of the ground is level, and upon vibrating rods where the surface is depressed. One of these vibrating rods is shown in Fig. 6404; they are arranged to stand vertically when the pump-pistons are at the bottom of their stroke.

It is obvious that in the above system of rods a very large proportion of the motive force is absorbed by the friction of the various parts, and that consequently only a low efficiency can be obtained. The loss of power from this cause is immense, even when the pit-work—that is, the whole system of pumps and rods—is kept in a perfect condition. But this is an extremely difficult thing to do. Some of the parts are continually getting out of order. Frequent repairs and alterations are needed, and these often necessitate a temporary stoppage of work, entailing much inconvenience and expense. This, added to a heavy first cost, makes the system a very expensive one. When considering the question of cost, it must also be borne in mind that this system requires a large shaft on account of the great space occupied by the pit-work.

Such are the defects inherent in the system of transmitting the motive force by means of rods. As we have already stated, many attempts have been made to supersede this system. One of the most successful is to take the engine underground and to force the water up at one lift. This is

no doubt, a very great improvement, as the loss by friction is reduced to a minimum, and the first cost, as well as the cost of maintenance, is lessened in a very great degree. This system is, indeed, free from most of the defects which we have pointed out in the Cornish pump. It has, however, defects of its own. The engine cannot be used for other purposes at the same time; in the case of metalliferous mines the coal has to be taken underground, and utter failure may result at a most critical time, namely, when a great and sudden influx of water or an outbreak of gas has driven the men out of the workings. Besides this, it is of course open to the objection of being inapplicable in the case of water power. To obviate these difficulties, another plan, a modification of the preceding, has been proposed, and in some instances successfully carried out. This consists in placing the boiler at surface, and conveying the steam down to the pumping engines through felted pipes. Where this system is applicable, it no doubt possesses considerable advantages over the preceding. But it is unsuitable for great depths in consequence of the condensation which must inevitably take place in the pipe; and, like the preceding, it is applicable only in the case of steam power.

Another system, the invention of G. G. André, has lately been introduced as a substitute for the rods, and from experiments recently made seems likely to prove very successful. It consists in transmitting the force developed by the motor at surface to the pump at the bottom of the mine through columns of water. There is, of course, nothing new in the principle of this system. The perfect manner in which force may be transmitted through pipes filled with water has been demonstrated by the well-known hydraulic machinery which owes its origin chiefly to the inventive genius of Joseph Bramah. And we have illustrated on page 1946 of the present work a system in which the employment of columns of water constitutes an essential feature. But all previous systems of this nature, though they have been applied to deep mines with considerable success, have possessed serious defects which have rendered them objectionable. These defects are—a somewhat complicated arrangement of the pumps; violent shocks occasioned by a sudden change of direction; liability of the pressure-pipes to lose water, and so to produce a vacuum beneath the motor-pistons, resulting in violent concussions; and a liability, from the same cause, of the pump-pistons to get displaced, as well as a want of a ready means of restoring the pistons to their position when so displaced. None of these defects exist in Andre's pump.

Pipes.—The pipes constitute an important part of a pump, and frequently represent a large proportion of the first cost. It is therefore essential to economy that they possess no excess of dimensions. The diameter of the pipes composing the rising main or pump-tree, and the thickness of metal, are dependent upon the quantity of water to be raised a minute, and the height to which it has to be lifted, and these must be calculated accordingly. The friction of the water in the pipes, which is one of the sources of a loss of power in a pump, is dependent upon the diameter of the pipes and the velocity of the water. This velocity should never exceed 4 ft. a second. Hence, in determining the dimensions of a rising main, the question of friction must be taken into account. In our article on Pipes we have entered fully into the subject of their manufacture and strength, as well as that of the friction of water, and we must refer our readers to that article for information on these matters. We would remark here, however, that in cases where no air-vessel is used to equalize the flow, the diameter must be calculated for the *greatest* and not the *mean* discharge. For example, suppose a 10-in. pump, worked by a crank, the path of which is 1 ft. in diameter, and the velocity of which is twenty revolutions a minute. The quantity discharged a minute is $78 \cdot 54 \times 12 \times 20 = 18849$ cub. in. $= 67 \cdot 8$ gallons. But during one-half of the stroke, the delivery is nothing, and it is a maximum at the centre of the other half, because the piston has then the velocity of the crank-pin. The path of the crank being $3 \cdot 1416$ ft. in circumference, the discharge at this point is $78 \cdot 54 \times 37 \cdot 7 \times 20 = 59219$ cub. in. $= 213 \cdot 2$ gallons; and it is for this discharge that the pipe must be calculated.

The Air-chamber.—We have already described under Air-chamber the use and construction of this contrivance for equalizing the flow of the water. We shall therefore treat it very briefly here. An air-chamber, by maintaining a constant flow, increases the efficiency of a pump. A single-acting pump, for instance, loses power in consequence of the piston having to set the superincumbent column of water in motion at each stroke. A double-acting pump is in this respect similar to the single-acting; but in a three-throw pump the flow is continuous, and, for this purpose at least, an air-vessel would in this case be a superfluity. But a more important use of a reservoir of air is to relieve the pressure, and so to prevent shocks. In this respect they are a very valuable adjunct to a pump, and they ought to be applied wherever practicable when the pressure is great. By practicable we mean, when no better substitute can conveniently be applied. For we hold that when it can be conveniently adopted, an accumulator in the form of a loaded piston affords a much better means of equalizing the flow and relieving the pressure. The air-chamber possesses the serious defect of requiring, in some cases constant, in others frequent replenishing, in consequence of the absorption of the air by the water. This necessity renders the construction of the chamber more complicated, and consequently increases its liability to derangement. The rapidity with which the air is exhausted in the chamber depends on the pressure to which it is subjected. The temperature is an element in the question; but as the temperature of water at a considerable depth beneath the surface of the ground varies but slightly, it may in this case be neglected. Common air is composed of 21 parts of oxygen and 79 parts of nitrogen; and of these elements, when under the ordinary atmospheric pressure of 15 lbs. to the square inch, water absorbs $\cdot 046$ of its own volume of the former, and $\cdot 025$ of its own volume of the latter. Hence it will be seen that when greatly compressed, as it is in an air-chamber, it will be rapidly absorbed by the water. Suppose, for example, the air in the chamber to be compressed sufficiently to exert a mean pressure of 60 lbs. to the square inch upon the walls. The air in this case will be absorbed by the water in the proportions of $\cdot 025 \times 4 = \cdot 100$ of its own volume, for the nitrogen, and $\cdot 046 \times 4 = \cdot 184$ for the oxygen. Therefore, unless frequently replenished, the action of the chamber cannot be maintained. In consequence of this property of water to absorb air, an air-chamber cannot be applied at all when the

pressure is very great, as in the case of high lifts in mines. Under such circumstances the loaded piston might often be advantageously employed.

To Calculate the Efficiency of a Reciprocating Pump.—We have shown that the load upon the piston of a pump is equal to the weight of a column of water whose base is the area of the piston, and whose height is the vertical distance from the surface of the pool to the point of discharge. The lifting of this weight constitutes the effective work of the pump. To ascertain what proportion this work bears to the total work transmitted from the motor, it is necessary to determine the other resistances which the pump has to overcome, and which may be called *passive* resistances, since they merely absorb force without producing any useful effect. These are;—1, the friction of the piston against the walls of the cylinder or the packing of the stuffing box; 2, the friction of the water in the cylinder and pipes; 3, the contraction of the fluid vein at its entrance into the suction-pipe, and at its passage through the water-way of the valve; 4, the weight of the valve; and 5, the inertia of the mass of water to be set in motion.

Besides the above, there is the resistance due to the friction of the rods, when the latter are employed, and this resistance is frequently greater than the whole of the other passive resistances together. But as it is very variable, depending as it does very much upon the state in which the rods are kept; and as, moreover, it is not common to all reciprocating pumps, we shall leave it out of the question. In determining the passive resistances, it is not intended to give rigorously accurate results; an approximation is all that can be attained to, but the approximation is sufficiently near for practical purposes.

The friction of the piston depends upon the nature of the materials and the pressure of the water. When the leathering consists of a simple cup-leather, its upper edge being pressed against the walls of the cylinder by the column of water resting upon it, the pressure is proportional to the height H. Also in other cases, and in general, the packing has to be tightened as the pressure increases, so that the friction still remains proportional to H. This proportion has been found by careful experiment to be about ·06 of the weight of the superincumbent water when the piston is in a good condition.

The friction of the water in the rising main of a pump is very nearly the same as that of the water in an ordinary water-pipe, and may therefore be found with sufficient accuracy from the formula $H = \frac{G^2 \times L}{(3\,d)^5}$, in which H is the head of water in feet due to friction, G the discharge during the effective part of the stroke in gallons a minute, L the length of the pipe in feet, and d the diameter of the pipe in inches.

The height due to the velocity of flow through a contracted passage is given by the formula $H = \left(\frac{G}{d^2 \times 13}\right)^2$ in which the letters have the same signification as above. Hence the resistance due to the contracted passages will be represented by $\left(\frac{G}{d^2 \times 13}\right)^2 + \left[\left(\frac{G}{d'^2 \times 13}\right)^2 - \left(\frac{G}{d^2 \times 13}\right)^2\right]$ d^1 being the diameter of the second contraction.

At the beginning of the up-stroke of the piston, when the water presses against the lower face of the sleeping valve, it meets with a resistance due to the weight of the valve. To overcome this resistance a force at least equal to this weight must be exerted against the lower face of the valve. To determine the height of the column of water representing this force, let us take, for greater generality, the case of a clack. Let W be the weight of the valve in lbs., l the distance of its centre of gravity from the axis of rotation, s the area of the water-way, l^1 the distance of its centre from the same axis, and x the height sought, the measurements being in feet. W l will be the moment of the resistance due to the weight of the valve, and $62 \cdot 4\, s\, x\, l^1$ will be that of the opposing force. And since the two forces must be equal, we shall have $W\, l = 62 \cdot 4\, s\, x\, l^1$. Deducing from this equation the value of x and multiplying it by $62 \cdot 4\, \pi\, D^2$ to find the force to be exerted by the piston, we get $\frac{W\, \pi^1\, D^2\, l}{s\, l^1}$. If the valve when closed instead of being horizontal makes an angle θ with the horizon, this expression must be multiplied by cos. θ. With a spindle-valve covering a circular orifice of diameter d, we shall have simply $W \frac{D^2}{d^2}$; and this value will be sufficiently exact for all practical purposes for both kinds of valves. As the valve has to be held open during the whole of the stroke, this force may be considered to be exerted during the whole of the time the piston is ascending.

The inertia of the water, which we have given as one of the resistances to be overcome, seldom occasions a loss of power, because usually the motion of the piston is regulated in this respect by the machinery to which it is connected. For instance, if it is driven from the crank of a wheel possessing a uniform motion, it starts from a state of rest with the water which it drags after it; it rises at first with an accelerated motion, and the acceleration gradually decreases until at the middle of the stroke it becomes nothing. The velocity is then retarded until it becomes nothing at the top of the stroke. During the first half of the stroke, the motion has acquired an accelerating force diminishing progressively, and during the second half a retarding force increasing according to the same progression, and sufficient to entirely destroy the effect of the former. Thus, what it has been necessary to take from the motive force employed to overcome the inertia of the mass raised during the first portion of the stroke, will be given back by the inertia of this mass to the same force during the second half; and therefore the inertia will not have occasioned any loss of force.

We will now show the application of the above principles and formulæ by means of an example. Let it be required to determine the sum of the resistances in a single-acting sucking pump, making twenty effective strokes a minute, and having the following dimensions;—Diameter of barrel, D = ·75 ft.; length of barrel, L = 5 ft.; diameter of suction-pipe, d = ·5 ft.; length of

suction-pipe, $L^1 = 20$ ft.; when $L + L^1 = H = 25$ ft.; length of stroke, $l = 4$ ft.; weight of sleeping valve, $W = 2$ lbs.

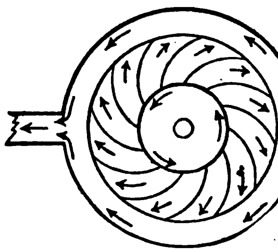
In this case the discharge is 220 gallons a minute. But as the pump is discharging during one-half of the time only, namely, during the up-stroke, this quantity must be double in calculating the resistances.

Weight of the column of water to be lifted $= 62\cdot4\ \pi' D^2 H$	=	686·25 lbs.
Friction of the piston $= 686\cdot25 \times \cdot06$	=	41·17 „
Friction of the water in the pipes (neglecting the barrel) $= H = \dfrac{G^2 \times L}{(3\,d)^5}$	=	24·46 „
Resistance due to contraction and velocity in suction-pipe $= H = \left(\dfrac{G}{d^2 \times 13}\right)^2$	=	11·17 „
Resistance due to weight of valve $= W\dfrac{D^2}{d^2}$	=	4·45 „
Total resistance	=	767·50 lbs.

The loss of power is thus about 11½ per cent. In the above case the diameter of the valve orifice is the same as that of the suction-pipe; consequently there is but one contracted passage.

Centrifugal Pumps.—Centrifugal pumps, as we have already stated, are merely water-fans, and therefore the principles which apply to a blowing machine will, with slight modifications, be equally applicable to a centrifugal pump. Fig. 6405 shows the action of one of these pumps. Supposing the pump to contain water, and the revolving disc of blades to be set in motion in the direction of the inner arrows, the water in the channels between the blades, as well as that between the edges of the blades and the outer casing or box in which they revolve, will be driven in the directions shown by the middle and outer arrows, and will thus be constrained to pass out through the opening provided for that purpose. The force with which the water flows out will obviously be equal to the centrifugal force developed by the revolving disc, which force is dependent on the velocity of revolution. As the water flows away from the centre a partial vacuum tends to form there, and this brings up the water from below. The height of suction should be small; for if the discharge due to the velocity of the blades is greater than the supply through the suction, the pump of course gets out of water and ceases to work. Wherever possible, it is better to avoid suction altogether, by placing the pump beneath the level of the water to be raised.

6405.



The form of the revolving blades or vanes has a great influence upon the efficiency of the pump. Originally they were made straight and affixed to the centre radially. But Appold, by the adoption of the curved form, more than doubled the efficiency. Other details of construction also materially affect the work of a centrifugal pump. As, however, these questions have been discussed, and some of the most approved models fully described under Hydraulic Machines, we must, to avoid repetition, refer the reader to that article for further information concerning the actual construction of this kind of pump.

As the height to which the water will ascend in the delivery-pipe is due to the centrifugal force developed by the revolving blades, it is evident that this height can never be great, and also that the velocity of revolution must in every case be considerable. Some cases have been recorded in which, by means of a very high velocity, a height of upwards of 50 ft. has been reached; but such heights are only the result of curious experiments. Practically, 20 ft. may be considered as the limit. The force with which the water ascends being equal to the centrifugal force, we have as the expression of the work done, $W = \frac{\omega^2 r^2}{2g} \times P = \frac{P v^2}{2g}$ P being the weight of the particle of fluid transferred by the centrifugal force from the axis of rotation to the extremity of the radius r, ω the angular velocity, and v the velocity of the extremity of the blades. Also, if we make $P =$ the weight of water passing a second, and V the velocity at the end of the blades in feet a second, we have, neglecting the loss by friction and other causes, $W = \frac{P V^2}{2g}$. In the best pumps this loss is about 35 per cent.; multiplying the preceding expression by ·65, we have $\frac{\cdot65 P V^2}{2g} =$ the effective work. Hence $H = \frac{1}{2g} \times \cdot65 V^2 = \cdot0155 \times \cdot65 V^2 = \cdot01 V^2$. If it be desirable to introduce the number of revolutions into the formula, we have, as already given, $V = \frac{2\pi r n}{60}$; whence $H = \cdot0012\, r^2 n^2$

Appold gives the formula $V = 550 + 550\sqrt{H}$.

The proper proportioning of the several parts of a centrifugal pump is a matter of great importance. J. Glynn gives the following as the most suitable dimensions;—Let r represent the external radius of the blades or radius of revolution; v the surface velocity of the blades, which must be proportioned to H the maximum dynamic head of water to be overcome, and which consists of h the height to which the water is to be delivered above the lower level, h' the height due to the velocity of delivery, and h'' the head due to friction and other resistances in the machine.

Then $\frac{v^2}{2} = H = h + \frac{V^2}{2g}\left(1 + \Sigma f\right)$, V being the velocity in the rising main Σf, the sum of the several resistances; and the surface velocity of the blades is $v = \sqrt{\left(2h + \frac{V^2}{2}\left(1 + \cdot 025\frac{h}{d}\right)\right)}$, d being the diameter of the pipe. When the pipe is not vertical its length l must be substituted for h. Taking the diameter of the rising main as unity, in proportioning the pump, let $r = \frac{7}{4}d$; the radius of the ears of the pump $= \frac{3}{4}d$; the breadth of the blades $= \frac{3}{4}d$ nearly; the diameter of each of the indraught passages $= d$, and the mean radius of the casing of the pump $= \frac{7}{4}d \times \frac{v}{V}$.

The power required to drive a centrifugal pump, and to raise a given weight of water W, a minute, is, taking the efficiency as 50 per cent., and only the best pumps exceed this,

$$2\,W\left(h + \frac{V^2}{2g}\left(1 + \cdot 025\frac{l}{d}\right)\right).$$

The diameter of the rising main and suction-pipe usually adopted is as follows for the sizes given;—

Number of gallons a minute ..	25	70	150	300	500	1400
Diameter of suction-pipe	2	4	5	6	7	8
Diameter of delivery-pipe	1½	3	4	5	6	7

One of Appold's centrifugal pumps 1 in. in diameter, and making about 6500 revolutions a minute, will discharge 10 gallons of water, while a 12-in. pump, having the same velocity at the circumference, that is, making $\frac{1}{12}$ the number of revolutions, will discharge 1440 gallons a minute, being according to the square of the diameter and not according to the cubic contents. Experiments have shown that the 12-in. pump will raise the water without discharging any, 1 ft. high with 159 revolutions, 4 ft. with 318, 16 ft. with 636, and 64 ft. with 1272 revolutions a minute.

The following Table giving the mean results of various experiments with Appold's 12-in. pump furnishes important information;—

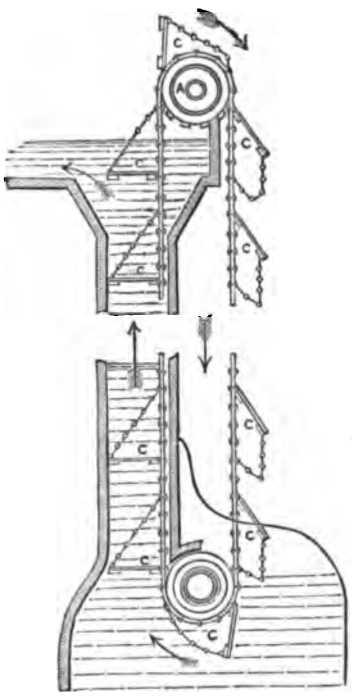
Number of revolutions a minute of 6-in. drum and pump.	Number of gallons raised 5 ft. 6 in. high a minute.	Equivalent in lbs. raised 1 ft. high a minute.	Strain in lbs. on a drum of 4 ft. diameter driving one of 6 in. diameter, as measured by a dynamometer.	Equivalent strain on the steam-engine rated in lbs. raised 1 ft. high a minute.	Percentage of work done compared with power expended.
400	500	27,500	74	44,400	61·7
412	600	33,000	80	49,440	66·7
427	700	38,500	87	55,723	69·
440	800	44,000	94	62,010	70·9
453	900	49,500	100	67,950	72·8
474	1000	55,000	106	75,366	72·9
481	1100	60,500	113	81,479	74·2
495	1200	66,000	118	87,615	75·3
512	1300	71,500	121	94,017	76·
535	1400	77,000	126	101,115	76·1
563	1500	82,500	134	113,163	72·9
580	1600	88,000	138	120,060	73·3
595	1700	93,500	142	126,733	73·6
607	1800	99,000	150	136,575	72·5

The efficiency of this pump, as shown by the results tabulated above, is unusually high. The majority of centrifugal pumps do not give a higher percentage than 50.

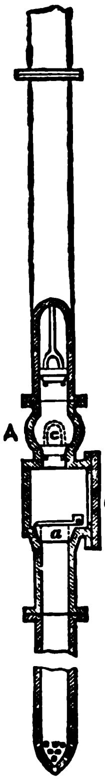
The Chain-pump.—The chain-pump consists essentially of a rectangular case or pipe, through which an endless chain works, bearing at intervals a rectangular plate of wood of slightly smaller dimensions than the inside of the pipe, and arranged to stand horizontally as it passes up through the pipe. Fig. 6406 represents one of Murray's chain-pumps, the most commonly employed in this country. The chain passes under a roller at the foot, and over a small pitch-wheel A at the top, by which it is driven through the medium of suitable gearing. The lifts C feather in passing over the wheel to the descending side, and unfold when brought round to the foot of the pipe on the ascending side. Thus the pump is enabled to take off the water with the same dip as other pumps. As will be seen by the figure, the lifts carry up the water above them in the pipe and discharge it into a trough at the top. To avoid friction, these lifts are made to work freely in the pipe or barrel, a play of about ¼ in. being left between their edges and the barrel. Thus there is a certain amount of slip; but as the chain is driven at a considerable velocity, this amount is not great. Experiments made by Lovick for the London Metropolitan Board of Works showed the slip to be about 20 per cent. The ordinary speed at which the chain is

driven is from 200 to 300 ft. a minute. From 10 to 12 ft. apart has been found to be the best pitch for the lifts; putting them nearer needlessly increases the complexity of the pump. This pump, which is remarkable for its simplicity, is very effective up to a height of 50 or 60 ft.

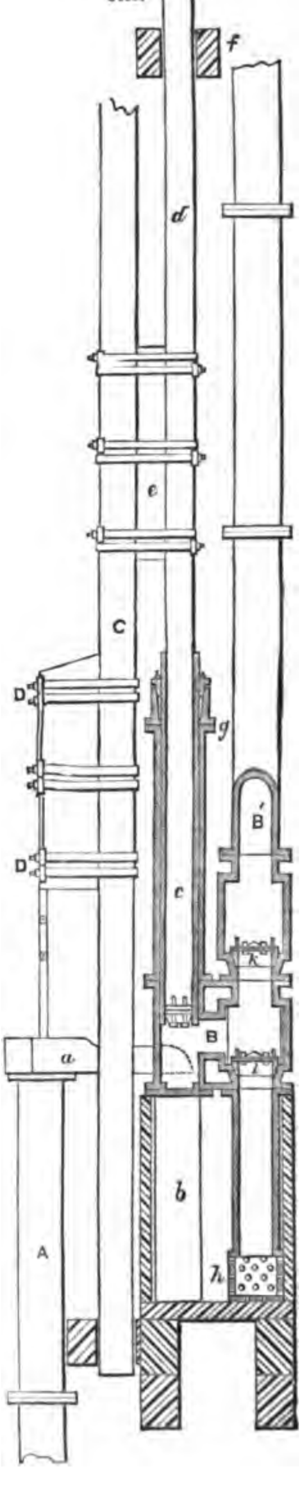
6406.



6407.



6408.



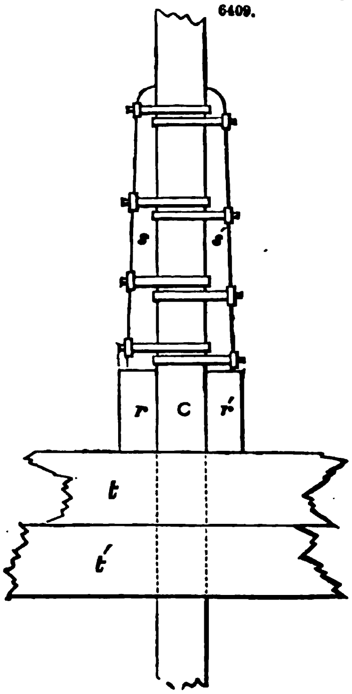
Lovick's experiments showed its efficiency to be about 63 per cent. of the indicated horse-power of the engine working it. One great advantage possessed by this kind of pump is its freedom from the liability of being choked.

Pumps for Draining Mines.—One of the most important uses to which a pump may be applied is the removal of water from the workings in mines. The carrying on of the whole of the underground operations is dependent on the several points of development being kept free from the water that is continually issuing from the water-bearing strata driven through, and the nature of these operations is such that pumps alone are available as the means of drainage. Hence it is essential that the pumps applied to this purpose should be capable of raising the maximum quantity of water entering in a given time, and be free from all liability to derangement. The circumstances, however, under which a pump so applied has to work is very unfavourable to the fulfilment of these conditions. The motor being situate at surface, and the pump at a great distance beneath it, the force developed by the former has to be transmitted to the latter through ponderous connecting rods of great length, as in the Cornish system of pit-work. Or where other systems are adopted, there yet remains a long length of water-pipes exposed to great pressure and frequent shocks, as well as to the strong corrosive action of water charged with various mineral substances. Thus the same degree of efficiency, with the same immunity from derangement, is not to be looked for in a mining pump as in one established in more favourable situations, and this fact must be borne in mind when estimating the merits and demerits of any system of mine-pumping.

The Cornish system was, until very recently, the only one applied to mining purposes. It consists, as we have already said, in having a pump at each level, and in working the whole of them simultaneously from one main rod. Figs. 6407 to 6409

show the details of this system. Fig. 6407 is the first or lowest lift, and is always of the lifting or common bucket kind. The reasons for the adoption of this kind for the bottom lift are—the facility with which it may be lowered as the shaft is sunk deeper, and the liability of the bottom lift to be drowned by a rise of water in the well, consequent on a stoppage of the pump for alterations or repairs. If a plunger-pump were used in this case, a rise of a few feet would cover the whole of its valves and working parts, and so render them inaccessible for repairs before the water was got under. But the bucket of a lifting pump can always be drawn up to the top of its rising main A, Fig. 6408, above which the water is not likely to rise before it is mastered. And as there is a contrivance for remedying, from the same level, any defect in the sleeping valve beneath the piston, the perfect working of the pump is secured until the water is lowered to its accustomed level. To enable the bucket to be drawn up readily, the rising main is about an inch larger in diameter than the working barrel, and the latter is made trumpet-mouthed at the top to facilitate the entrance of the bucket when lowered from above. The clack-valve *a* is accessible, when the level of the water permits, by a door *b*. When, however, the water rises above this door, and the valve *a* gets out of order, the contrivance alluded to above must be resorted to.

6409.



In the clack-piece below the barrel at A, the bore of the pipe is contracted at *c* to a size a little smaller than that of the working barrel, and thus made slightly conical. A drop-valve made to fit this bore may then be dropped down through the pipe and barrel to its seat, as shown in the figure in dotted lines. The action of the pump may be continued by means of this temporary valve until the water has been sufficiently lowered to render the fixed valve *a* accessible. The drop-valve is provided with a loop or handle, to enable it to be easily drawn up.

The bucket-rod passes up the rising pipe A, Fig. 6408, and is fixed to the main rod C by means of a set-off and iron straps D. In this lift, the water is raised by the up-stroke of the rods through the pipe A, whence it is discharged by the trough or collar-launder *a* into the cistern *b*.

The second lift is a plunger-pump, and it takes its water from the cistern *b*. As this cistern receives the water which drains into it from the level on which it is placed, the second pump must be of larger capacity than the first; and this is the case with each lift in succession. Fig. 6408 is a section of one of the plunger-pumps. The plunger *c* is driven upon the wooden rod *d*, or, as it is technically termed, pole, and made tight by wedging into the bottom end. This pole is fixed to the main rod C by means of a set-off *e*, and iron straps and nuts. A guide *f* keeps the pole in a true line with the axis of the barrel, or, as it is called in Cornwall, pole-case.

When the plunger ascends, the water is sucked in through the wind-bore *h* and valve *l* into the double pipe or H-piece B, whence it is expelled by the descent of the plunger through the delivery-valve *k*, and rising main B′, which conducts it up to the cistern on the next level above. As all the other lifts are precisely similar to this one, they need no description. The height of each lift is usually from 30 to 40 fathoms. The main rod, as already described, works through guides fixed at intervals down the shaft, and that the friction of the rod against these guides may not be excessive, the former must be well made, firmly put together, and truly hung. At the top it is hung to the gudgeon of the outer end of the engine beam, or to the arm of a double V-bob, as shown in Fig. 6403. The excess of weight above what is required to raise the water is taken off by means of balance-bobs, as shown in Fig. 6402. At intervals down the shaft side pieces are strapped to the main rod, as S, S′, Fig. 6409; these serve a double purpose. Their primary use is to prevent the rods from descending too far, and so causing injury to the pumps and to the engine. When the rods have descended sufficiently low, the side pieces come to rest upon the blocks *r*, *r′*, which are supported by the timbers *t*, *t′*, let into the sides of the shaft. But another important use is to prevent the rods from falling down the shaft in case of fracture; for should the main rod break at any point, the portion below the rupture would be supported upon the blocks, and thus incalculable mischief would be averted.

The joints of the pipes are always flange-joints. To render the joint water-tight, a ring of lead or wrought iron, which has been previously wrapped round with a piece of common woollen cloth, and afterwards dipped in tar, is inserted between the flanges. The joint thus formed is very sound and durable, and it admits of being taken apart with the greatest facility.

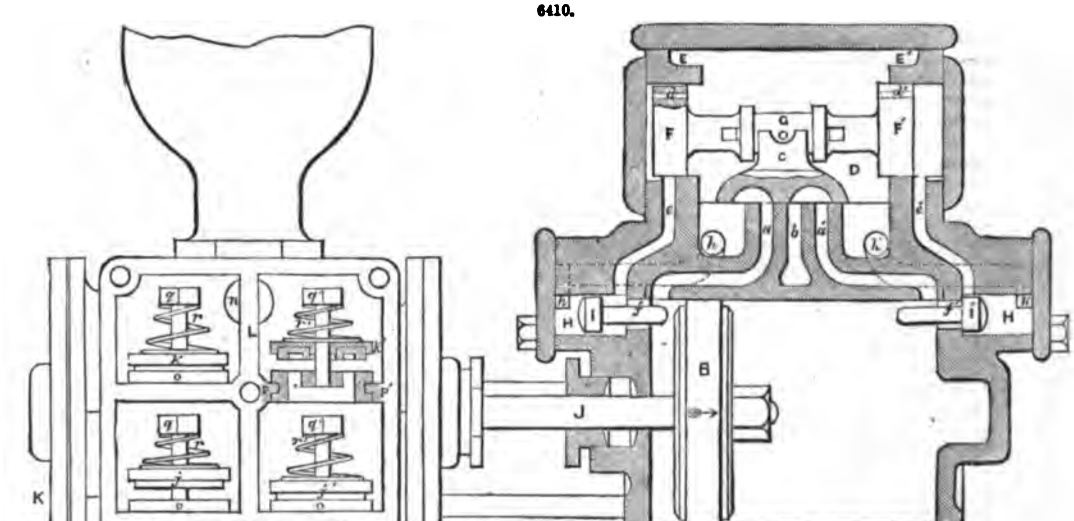
To preserve the pipes from the corroding action of the mineral water, it is usual to line them with a thin casing of wood. The mode of putting in the wood is to place it in the form of staves, like those of a cask, round the interior of the pipe, leaving a small space between the last and the first inserted. Two wedges are then driven into this space from the two ends of the pipe by simultaneous blows of a hammer. This simple operation is sufficient to keep the lining firmly in its position.

The system of pump which we have been describing is in some respects very suitable for the purpose to which it has been almost exclusively applied, namely, the draining of mines. It possesses no delicate parts, and it is of so simple a nature that any alterations or repairs may be effected by the most inexperienced hands. This is an important advantage in a mining pump.

Another advantage claimed for it is the ability to take the water from each of the levels or stages in a mine. This advantage, however, has its compensating defect in the additional number of pumps required, and the greatly increased friction resulting therefrom. Beyond this the system has little to recommend it; its first cost is great, and the cost of its maintenance is also great. The ponderous rods require constant attention and frequent repairs; they occupy a large portion of the space in the shaft; they must be counterweighted by balance-bobs, placed in cavities excavated horizontally in the sides of the shaft—a very expensive situation—and they are the source of great loss of power from friction. Also the mode of working the pumps by raising the rods and using their weight to force up the water is false in principle. It is lifting a heavy weight in order that by its fall it may bring up a less one. This may be the best mode of working the Cornish system of pumps; but it is working at a loss nevertheless. That there may be no hitch in the working in consequence of obstructions, the excess of weight to be lifted must be considerable. Thus the total amount of loss from friction, and other causes, constitutes a very large percentage of the motive force. And as in the case of steam power the loss of motive force is represented in the fuel consumed, this loss forms an important item in the cost of working. When water power is employed, one-half of the effective power of the wheel is lost altogether when, as is often the case, only one set of pumps are driven from the wheel. As the crank by which the main rod is raised works through only one-half of its revolution, the whole of the water expended during the other half of its revolution is sheer loss; and this loss is in addition to that from friction and the other causes alluded to above. Another disadvantage of the system is the difficulty of changing the direction of the motion. The multiplication of V-bobs is attended with great inconvenience and loss of power, and beyond a very slight degree is impracticable. This difficulty of changing the direction often necessitates the sinking of a shaft in a direction suitable for the pit-work rather than in that which is more favourable in other respects. These defects render the system of pumping by means of rods a very imperfect and expensive one; and the desirability of substituting for it a more efficient system has led to the introduction of several others to which we have already referred.

Underground pumping-engines are represented by the "Special pump" manufactured by Tangye Brothers, and the "Universal Pump," invented by E. Cope and J. R. Maxwell, of Ohio, and made by Hayward Tyler and Co. Both of these are of very simple construction and of great power. Fig. 6410 is a longitudinal section through Tangye's Special pump. A represents an ordinary steam-

6410.



cylinder provided with a piston B. Steam is admitted to this cylinder through ports a, a', and it exhausts through the port b; and these ports are opened and closed by the action of the slide-valve c, which is of the ordinary construction, and which may be so arranged as to admit steam under the valve, as in the figure, or which may be constructed in any other suitable manner. This slide-valve is seated on the bottom of the steam-chest D, the ends of which form small cylinders E, E', bored out to receive small pistons F, F', which are connected to each other by a rod G, and this rod is provided with two collars to straddle a standard c which rises from the back of the valve. Small channels d, d', passing through the pistons F, F', form a communication between the interior of the steam-chest and the outer ends of the supplementary cylinders E, E', so that the small pistons are exposed to a uniform pressure of steam from all sides. The supplementary cylinders E, E', communicate through channels e, e', with chambers H. H', in the cylinder-heads, and communicate with the interior of the main cylinder A by means of openings f, f'; these chambers are bored out to receive piston-valves I, I', the stems of which project through the openings f, f', into the main cylinder A, and they communicate by means of channels h, h', with the interior of the steam-chest D;

the channels being so situate that the outer ends or heads of the piston-valves I, I', are continually exposed to the pressure of the steam which fills the valve-chest. By this pressure the piston-valves are forced towards the inner ends of the chambers H, H', whenever the inner ends of these chambers communicate with the exhaust end of the cylinder, and in this position the piston-valves close the channels *e*, *e'*, leading to the supplementary cylinders F, F', as shown in the figure, where the valve I' is represented in position to close the channel *e'*, the main cylinder being represented to take steam through the port *a*, and to exhaust through ports *a'*, *b*. As the piston reaches the end of its stroke it comes in contact with the end of the stem of the valve I', which it pushes out into the chamber H', the channel *e'* is thrown open, and the outer end of the supplementary cylinder E' is brought in communication with the exhaust-port *b*. By these means the equilibrium of the small pistons F, F', is disturbed, and the steam acting on the outer head of piston F, causes these pistons, together with the valve, to change their position. The motion of the main piston is reversed, and as soon as that end of the main cylinder containing the piston-valve I is brought in communication with the exhaust-port *b*, the live steam pressing on the outer head of that piston-valve causes the same to fly in and close the channel *e*. In the meantime, the steam passing through the small channels *d*, *d'*, in the supplementary pistons F, F', restores the equilibrium of the small pistons until the main piston, by coming in contact with the stem of the valve I, produces the subsequent change.

The steam-piston B connects by a rod J with the pump-piston which works in the cylinder K. By placing the mechanism for changing the steam-valve in the interior of the steam-cylinder, the piston-rod J can be made very short, and the two cylinders A and K can be brought close together. The pump-cylinder K is provided with a valve-chamber L containing four valves *j*, *j'*, *k*, *k'*, and communicating with the ends of the cylinder through channels, with the suction-pipe through an aperture *m*, and with the delivery-pipe through an aperture *n*. All these channels and openings are exposed by removing the bonnet, so that they can be readily kept clean, and the correct operation of the pump ensured with little trouble.

The valves *j*, *j'*, *k*, *k'*, are constructed of discs, which are provided with annular recesses to receive a packing of india-rubber or other elastic material; this packing projects beyond the face of the valve, as shown in the figure, and if the valve comes down on its seat the packing forms a tight joint, and the valve is prevented from coming in metallic contact with its seat on account of the incompressibility of the rubber or other packing confined in its recess. The seats *o* are cast of brass or other suitable material independent of the pump, and they are faced off and then cast into the lining, so that they require no further attention when the pump casting is received from the foundry. In order to retain the seats firmly in their places, they are provided with grooves P, P', in their peripheries. The cast iron which composes the pump runs into these grooves and retains the seats. The valves *j*, *j'*, *k*, *k'*, are held in the proper position in relation to their seats by pins *q*, *q'*, which screw into the centres of the seats; and, if desired, springs *r* may be applied to hold the valves down upon their seats.

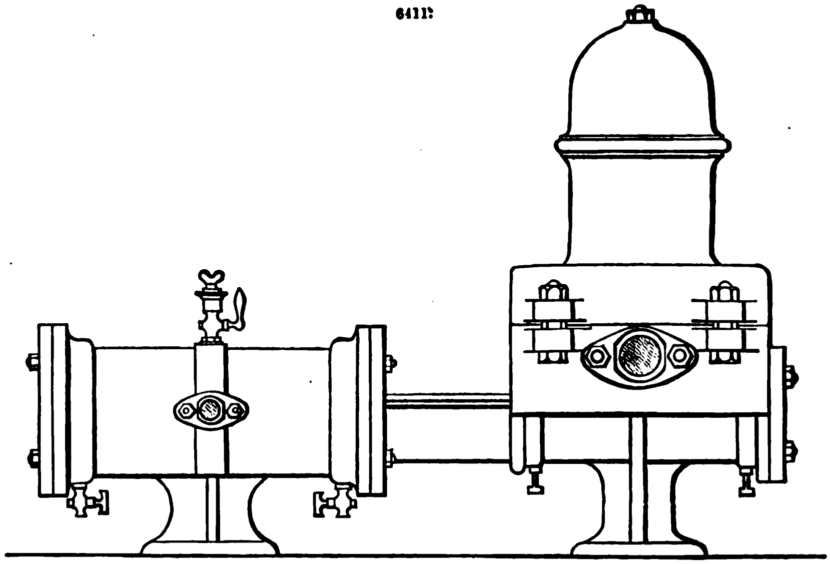
The play of the pump is very simple, and will be readily understood. When the steam-piston moves in the direction of the arrow, the valve *j* opens to admit water from the suction-pipe, and the water in front of the pump-piston is forced out through the valve *k'* and through the delivery-pipe. When the steam-piston moves in the contrary direction, the valves *j'* and *k* open and the valves *j* and *k'* close. The pump constructed for the Adelaide Collieries at Bishop Auckland, has a steam-cylinder 26 in. diameter, and the pump, which is double-acting, is 6½ in. diameter, with a 6-ft. stroke. The engine-room is situate at a depth of 1040 ft. beneath the surface. It is an arched chamber, 100 ft. long by 20 ft. broad, and 10 ft. high at the centre. The boiler, which is double-flued, 27 ft. long and 7 ft. in diameter, is erected at the far end of this chamber, and the pump is placed between the boiler and the shaft. Thus the height to which the water has to be raised is 1040 ft., and this is done in one lift at the rate of 130 gallons a minute.

The Universal pump may be taken as the representative of the system of working the engine underground by steam conveyed through felted pipes from the generator at surface. Of course, this is not an essential feature in the Universal pump. If it will work with steam conveyed from surface, it will work with steam generated in an engine-room under ground, as in the case of the Special pump. But it has been largely applied in this system, and is widely known in connection with it. Fig. 6411 is an elevation of one of these pumps. It is remarkable for the extreme simplicity of its parts. As in the Special, the only portion of the mechanism exposed to view is a few inches of the piston-rod between the steam and pump cylinders, and this portion is protected from blows by a half-cylindrical casing. Another remarkable feature is its compactness. A pump with a 15-in. steam-cylinder and a 12-ft. pump-cylinder, capable of raising 28,000 gallons an hour, occupies a space of only 8 ft. 4 in. by 3 ft. 1 in., the weight of such a pump being only two tons. This is a great advantage in all cases, but especially in mining operations, and as they are self-contained, they require but little foundation. These qualities render them peculiarly suitable for placing in the workings, as they occupy little space, and may be easily moved forward as the heading advances.

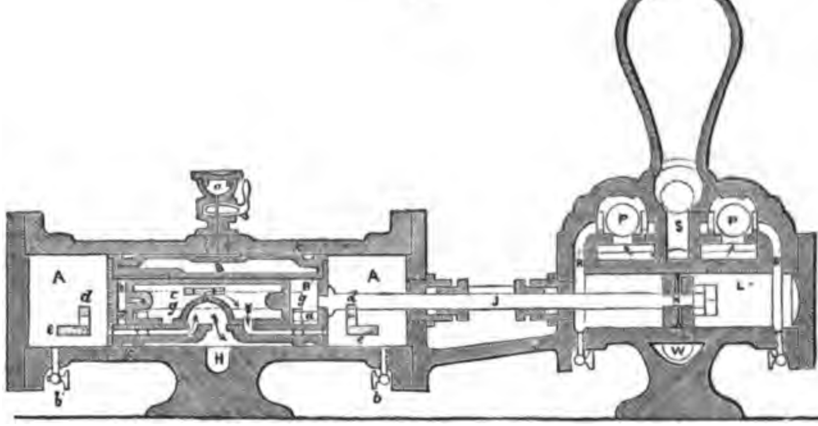
The essential feature of the Universal pumping engine consists in having a cylinder and piston so suited to each other that the piston will perform the functions of a valve in opening and closing the ports of the inlet and exhaust passages. This is accomplished by making the piston as much longer than the stroke as is required to cover the steam-ports at each end and exhaust-apertures in the centre of the cylinder lengthwise alternately at the same time when in operation. Besides this, there is an arrangement of steam-passages to the interior of the piston, in which a piston-valve is so arranged with its steam-passages and cavities as to properly communicate with the passages in the piston to change and direct the flow of steam alternately to each end of the cylinder for the purpose of producing the reciprocating movement of the piston without external valve-gear. The nature and construction of the various parts will be better understood by reference to the accompanying figures.

Fig. 6412 is a longitudinal sectional view through the steam-cylinder and pump; Fig. 6413 is a plan showing the steam-cylinder and piston in section, and the pump with air-vessel

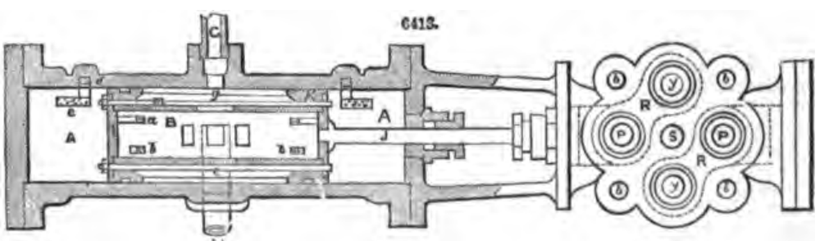
6411.



6412.



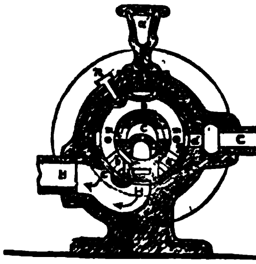
6413.



removed; Fig. 6414 is a transverse section of the steam-cylinder, piston and valve. A A is the steam-cylinder, B the piston, and C the piston-valve within it. G is the steam inlet-pipe, and H the exhaust-pipe; *m*, *m*, are rods connecting the covers I, I, of the piston; *k*, *k*, springs surrounding the ends of the piston; *a'* is a lubricating cock, and *b'*, *b'*, are drain-cocks; *o* and *n* are guide-pins for preventing rotary motion in the piston-valve and piston. The action of the steam in the cylinder and the working of the piston is as follows:—Steam enters through the inlet-pipe G, Fig. 6414, and has constant access to the interior of the piston through the aperture *d* and the elongated slot *g* in the side of the piston. It also enters the interior of the piston-valve through the rectangular

opening *h*, which is in constant communication with the inlet-pipe. It should be remarked that this aperture is made above the centre of the piston-valve in order that the steam may exert a pressure downwards greater than in any other direction, and thereby cause the bottom surface of the piston-valve to slide steam-tight. The steam passes down the ports and passages, as shown by the arrow, and thereby has access to one end of the piston, causing it to make a stroke. On or near the termination of the stroke, the piston causes the elongated slot *g* in its side to pass over the opening *d* in the side of the cylinder, communicating by a passage with the opening *e*, over which passes, simultaneously with the latter, an orifice and passage *a* in the piston leading directly to the inner chamber wherein the piston-valve works. Hence the steam gets access to the back of the piston-valve, and forces it to the opposite end of its traverse; the steam on the opposite side having at the same time free access to the exhaust-pipe through the passage *b b* in the piston, similar to the passage *a* before mentioned, which passage *b b* passes over a corresponding aperture *c'* in the centre of the length of the cylinder. Thus the piston-valve, on the principle of the D-slide, changes the direction of the steam, at the same time opening the exhaust communication, and causing the piston to make a return stroke, the steam escaping, as shown by the arrows, down through the aperture and the exit-pipe H. A certain amount of lead is given to allow the steam to exhaust before steam enters on the other side. This is accomplished by permitting the passage *c'* to communicate with each exhaust-passage leading to the back of the piston-valve a little before the slot *g* covers the aperture *d*.

6414.



6415.

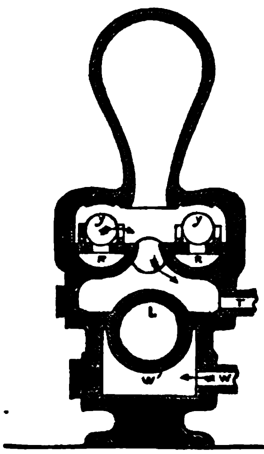


Fig. 6415 is a transverse section of the pump, a longitudinal section of which is shown in Fig. 6412. A suction-pipe W is affixed either side of the chamber W', as may be necessary, a portion of which chamber is below the barrel of the pump, and communicates by passages outside and surrounding both sides of the barrel with the suction-valves P, P, from where it has access to either end of the pump. The water is thence forced up the passage R' and through the passage R, the latter of which has a diagonal and horizontal direction leading to the delivery-valves *y*, *y*, whence it enters the chamber S. To this chamber a discharge-pipe T is affixed, capable of being used on either side to suit convenience. This arrangement of the water-passages and valves, so that the suction and delivery pipes can be attached to either side of the pump, allows the valves to be got at for repairs or other purposes without breaking and renewing pipe-joints.

This pump works with remarkable ease, on account of there always being a cushion of steam at the instant of reversal, both in the case of the valve and the main piston. It is readily erected and as readily removed; it occupies but little space, does not easily get out of order, and altogether may be taken as a good example of the system of underground pumping engine at present existing. The defects inherent in this system we have pointed out already when considering transmission of motion.

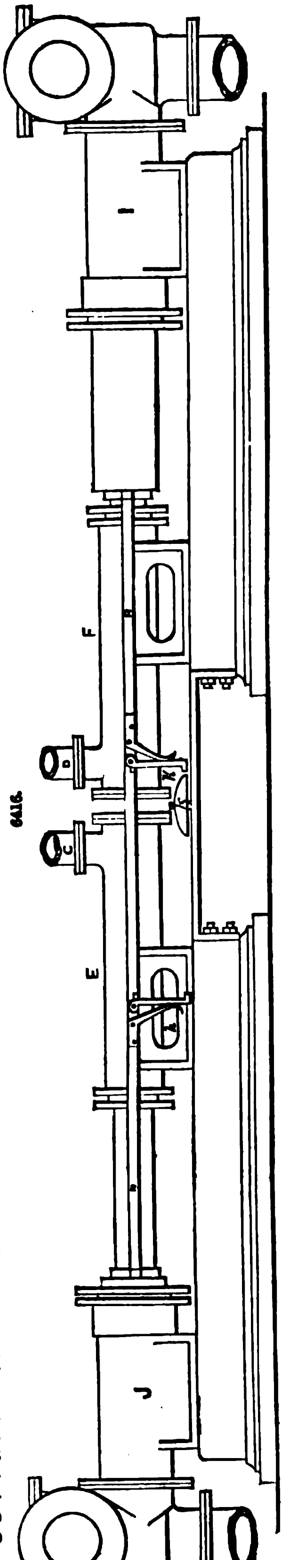
André's system of mine pumping machinery, manufactured by Sara, of Penrhyn, Cornwall, is shown in Figs. 6416 to 6418. Fig. 6416 is a side elevation, and Fig. 6417 is a plan, of the pump as fixed in the mine.

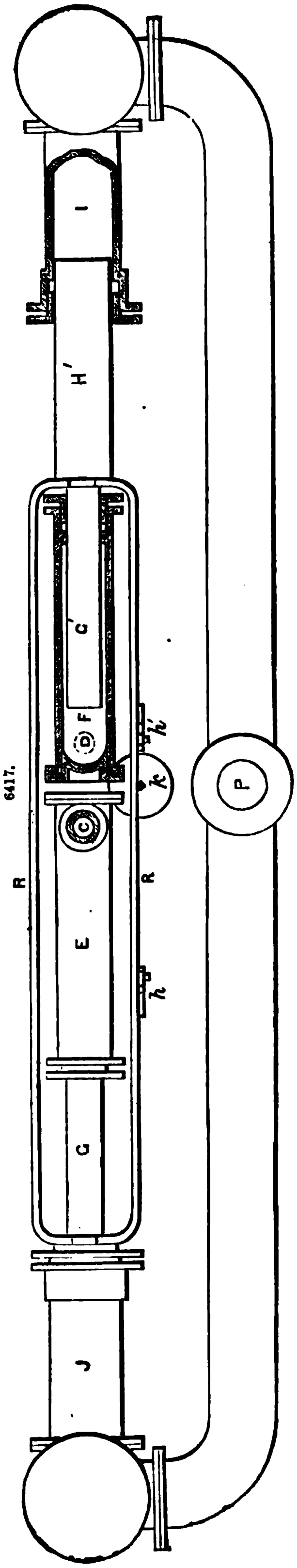
Two columns of water of equal height, and therefore balancing each other, communicate through the pipes C and D, called the pressure-pipes, with the interior of the cylinders E and F. These columns press by their weight upon the rams G and G' working through stuffing boxes in the cylinders E and F, and as the rams are connected outside by the rods R, R, they are held in equilibrio by that pressure. The continuation of these rams is of larger diameter, as shown at H', and works through stuffing boxes in the pump-cylinders or working barrels I, J. These barrels are provided with suction and delivery valves in the usual way. It is evident that if pressure be applied alternately to the columns C and D, a reciprocating motion will be communicated to the rams G and G', and thence to the plungers, which are merely continuations of the rams. Suppose, for example, pressure applied to the column D. The ram G' in cylinder F is forced back and the plunger H' expels the water contained in the working barrel I through the delivery-valve and up the rising main P. At the same time, the ram in cylinder E is drawn in by the rods R, R, and the plunger G sucks the water into the barrel J, the pressure-column C rising with the return of the ram. When the stroke is completed, the pressure is transferred to the other column C, and the same effects are produced in the contrary direction. Thus the pump is double-acting.

One mode of applying pressure to the columns is shown in Fig. 6418. Two cylinders, A and A', of the same diameter as the ram-cylinders E, F, are connected with the upper ends of the pipes C and D by a trumpet mouthed connection of the form of the contracted vein. These cylinders, called motor-cylinders, are placed vertically in the figure, in order to show the arrangement more clearly, but in practice the horizontal would in most cases be a more convenient position. Two plungers, B and B', work through stuffing boxes in these cylinders from a two-throw crank R and R'.

Thus it will be seen that the whole of this machinery is of a very simple character. The great difficulty, however, with a pump of this nature is to keep the pressure-pipes quite full of water,

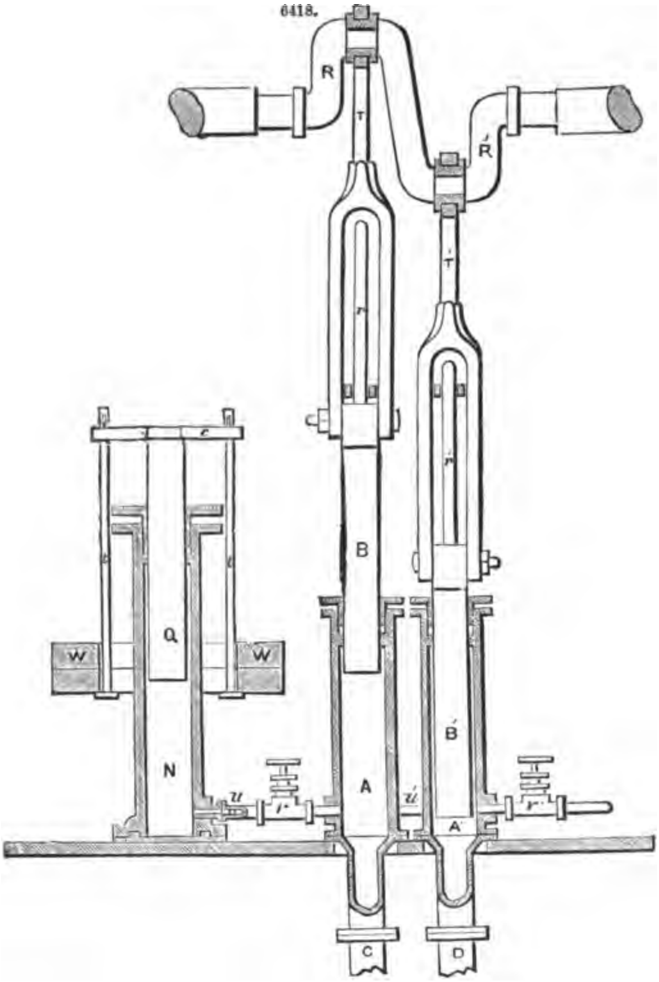
and also to preserve an equal quantity in each of the pressure-cylinders E and F. For if the pipes are not always full, violent shocks will be occasioned by the plungers B and B′ not meeting with water at the beginning of their stroke; and if from leakage one pipe has less water in it than the other, the rams in the cylinders E and F will be displaced in the direction of that pipe, and so endanger the machinery. This difficulty has been the chief cause of the failure of all previous attempts in this direction. In the system we are describing, this difficulty has been overcome in several ways. One of these is shown in Fig. 6418. The motor-cylinders are in constant communication with a reservoir-cylinder N, through the pipes *u* and *u′*. These pipes are provided with valves or cocks *v*, *v′*, worked by hand, for the purpose of cutting off the communication when necessary. A ram-piston Q works in the reservoir-cylinder through a stuffing box, and is loaded to the proper pressure to the square inch, which has been found requisite to work the pump, the weight W being suspended from the cross-head *c* by the rods *t*, *t′*. As the water in the motor-cylinders is in constant communication with that in the reservoir N, any leakage that may occur in the pressure-pipes or the pumps is instantly replaced. Consequently the pipes must be always full, and as no inequalities can possibly occur, the rams in the cylinders E and F cannot be displaced. As an additional safeguard, however, in view of a displacement occurring from other causes, such as an accident to any part of the machinery, a contrivance has been provided for signalling the derangement and restoring the equality. Upon one of the connecting rods R, Fig. 6417, are two levers or hammers *h* and *h′*, held up by springs against stops on the rod R. If the rams get out of their normal position, the hammer *h* or the hammer *h′* will strike the bell *k* at each stroke until the derangement has been remedied. This is effected by means of the valves *v*, *v′*, Fig. 6418, and a discharge-cock on each of the motor-cylinders. These discharge-cocks are not shown in the drawing. Suppose the pump-rams to be displaced in the direction of the pressure-pipe C in consequence


6418.


6417.

of a loss of water in that pipe. Cut off the communication between the motor-cylinder A′, by closing the valve V′, and open the discharge-cock on that cylinder. The pressure in the reservoir-

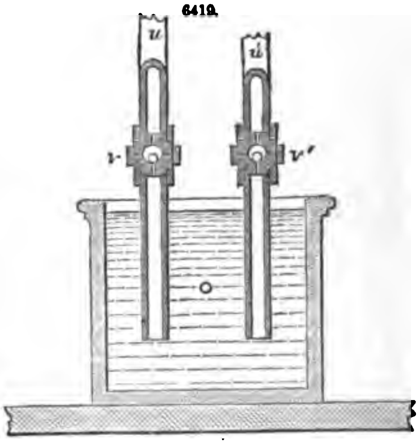
6418.



cylinder will then force the rams back to their normal position. Another mode of signalling or preventing displacement of the pump-plungers is to place a kind of spring buffer upon the connecting rods. Should a displacement occur, the buffer comes in contact with a standard or stout stud projecting from the bed-plate, and as further motion in that direction is stopped, the accumulator N takes the motive pressure; the consequent rise of the loaded piston indicating that the pumps are not making their full stroke.

Besides the purposes we have described, the reservoir-cylinder with its loaded piston serves the very important one of preventing a shock at each change of stroke. Also in the case of a hitch occurring in the pumps, the reservoir would take the pressure from the motor-cylinder, and so prevent a rupture. A small force-pump, worked by an eccentric from the same crank-shaft as the driving rams, supplies water to the reservoir.

6419.



Another contrivance for keeping the pressure-pipes full of water is shown in Fig. 6419. The part of the motor-cylinder just beneath the stuffing box is connected by a pipe *u* and *u′* to a cistern O. These pipes are each fitted with a ball-valve *v* and *v′*. A leakage in either of the pressure-

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